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Proceedings of the IRE

SKY WAVE PROPAGATION AT VLF: Page 1624

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- NEGATIVE L AND C IN MASERS
- VLF PROPAGATION THEORY
- NEGATIVE RESISTANCE CIRCUITS
- PHASE-STABLE OSCILLATORS
- STEP RECOVERY DIODE
- FREQUENCY SOUNDING TECHNIQUES
- TRANSACTIONS ABSTRACTS
- ABSTRACTS AND REFERENCES

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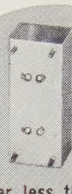
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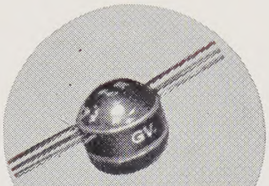
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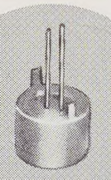
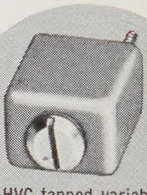

Toroid for printed circuit, Q of 90 at 15 KC.

Dual toroid, Q of 75 at 10 KC, and Q of 120 at 5 KC.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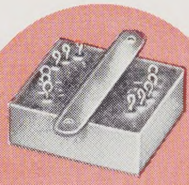
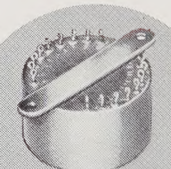
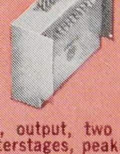

Voltage reference transformer .05% accuracy.


Multi-control magnetic amplifier for airborne servo.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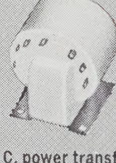
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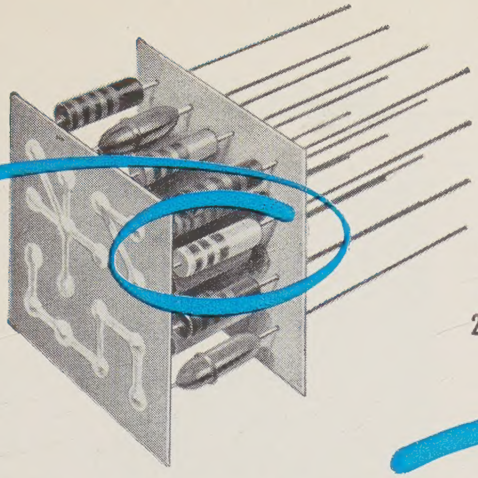

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Our research in materials for space applications at AIL requires precise methods of measuring evaporation and sublimation rates of various materials in high vacuum. This month Dr. M. M. Freundlich of our Aerospace Systems Department describes a universal microscale he developed for this purpose.

Microscale

During our extensive studies of space lubrication it was observed that, although most commonly used oil lubricants evaporate quickly in vacuum, some oils evaporate extremely slowly and can be operated for thousands of hours as bearing lubricants in high vacuum. These wet lubricants have a limited useful temperature range compared to some of the more unconventional dry lubrciants, but they have superior qualifications in a great number of applications. In our search for new and better wet space lubricants, our first step has been to select the most promising candidates by measuring their evaporation rates before subjecting them to further tests. To do this we have developed a vacuum microscale that has some unusual features.[*]

The microscale permits precise measurement of the rate of evaporation during the evaporation process. This is necessary because most oils are not pure substances but are composed of a large number of fractions having different molecular weights, different vapor pressures and different evaporation rates. The rate of evaporation is highest at the outset and can decrease during the process by many orders of magnitude.

Figure 1 shows a photograph of the vacuum microscale, and Figure 2 shows a schematic of the layout. A sample of about 0.5 gram of the fluid under investigation is placed in a small, thin-walled bucket. The bucket is suspended by means of a thin tubing from a dual spring. The two concentric coils of the spring have a spring constant of 0.7 inch per gram. Evaporation rates are measured by determining minute weight changes during selected measured time intervals. This is done by means of a linear differential transformer and a MICRO-trol[†] circuit, capable of measuring changes in position of two micro-inches or weight changes down to three micrograms. Gross sample weights are determined for each measured point by mounting the coils of the differential transformer on a moveable platform and by adjusting its position until the MICRO-trol circuit gives a zero reading. The platform is moved by a knob on the top plate of the vacuum chamber which turns a ball lead-screw via a magnetic coupling. The microscale permits, therefore, to relate each evaporation rate measurement to the percentage of sample evaporated.

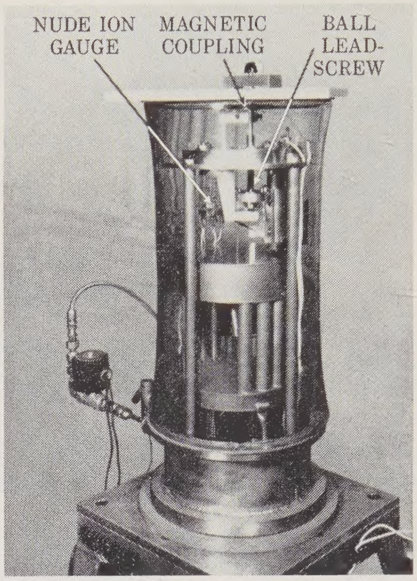

FIGURE 1

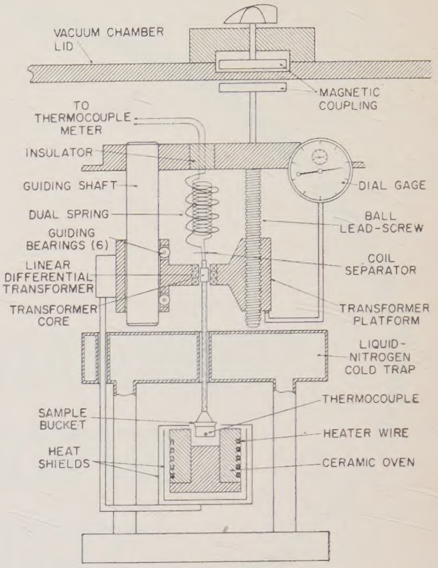

FIGURE 2

Evaporation rates vary widely with the temperature of the fluid. The rate curves are, therefore, taken at several temperature levels maintained constant for each test run. The sample bucket is heated from the underside by an electric heating element. The temperature of the fluid is measured and regulated by a thermocouple placed inside the bucket, using the two suspension springs as thermocouple leads.

The sample bucket is suspended just below a liquid nitrogen cold trap. The surface of the evaporating fluid thus faces nothing but a cold wall, which insures that the molecules leaving the fluid surface are condensed and cannot bounce back into the fluid.

To check the accuracy of the microscale we evaporated an extremely pure sample of n-Heptadecane. We measured its evaporation rate to:

$$G = 7.7\ 10^{-6}\ \text{gram cm}^{-2}\ \text{sec}^{-1} \quad \text{at } 22°\text{C} \ldots (1)$$

From this we determined its vapor pressure, using the well-known Langmuir equation, to:

$$P = 1.47\ 10^{-4}\ \text{torr at } 22°\text{C} \ldots (2)$$

We then calculated its vapor pressure directly from its published Antoine equation to:[‡]

$$P = 0.95\ 10^{-4}\ \text{torr at } 22°\text{C} \ldots (3)$$

Since the Antoine equation was derived from measurements in the pressure range from 10 to 1500 torr and has to be extrapolated to 10^{-4} torr, we consider the agreement between our measured value (2) and the calculated value (3) very satisfactory.

The microscale has been used principally for evaporation rate measurements in high vacuum under controlled temperature conditions, but we believe that it can be used equally well in many other situations where remote measurements are required.

[*] Note: Part of this development was carried out under USAF contract AF33(616)-6845 for the Materials Laboratory of ASD-AFSC.

[†] AIL Trademark.

[‡] Note: See F. D. Rossini et al. "Selected Values of Physical and Thermodynamic Properties of Hydrocarbons and Related Compounds"; Carnegie Press, p. 337, 1953.

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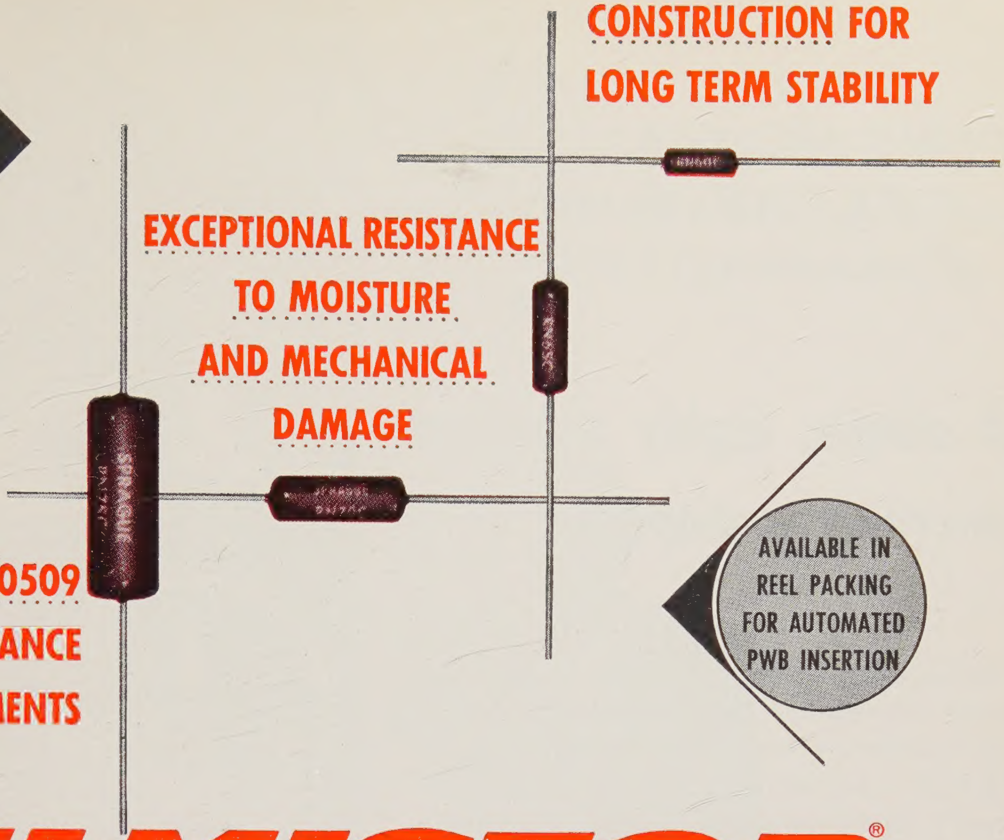

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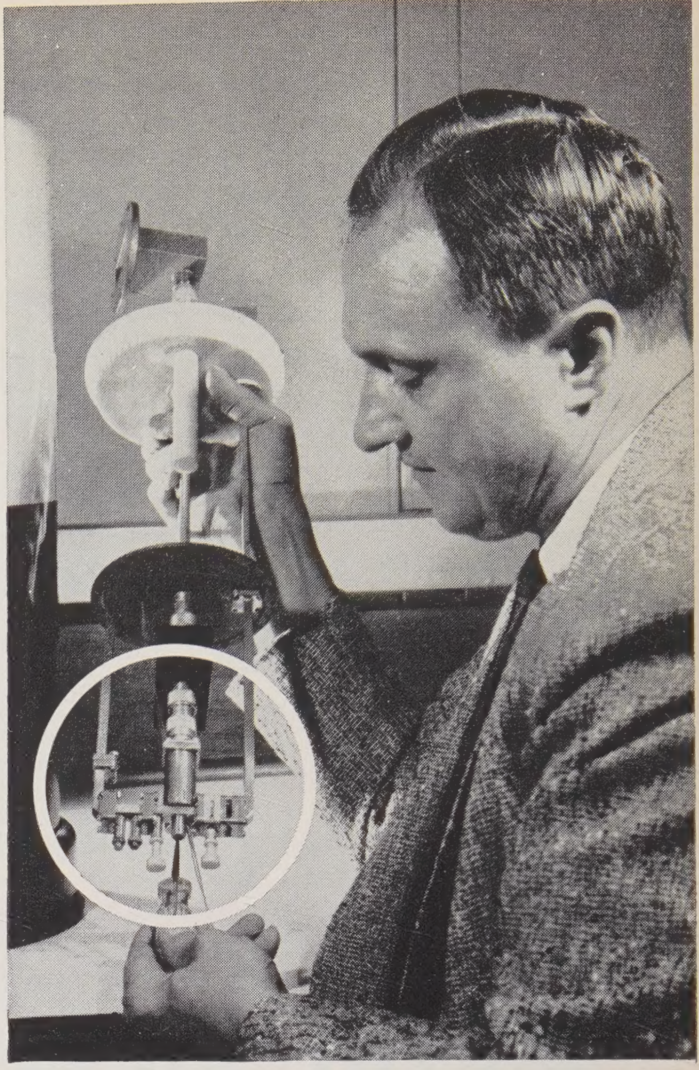
NEWS FROM BELL LABORATORIES

A simple, highly sensitive microwave amplifier



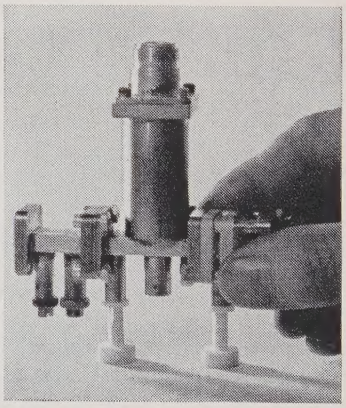
Bell Laboratories' Michael Chruney adjusts waveguide assembly (in circle) housing the diode. After adjustment the entire parametric amplifier will be immersed in liquid nitrogen in dewar at left. The new amplifier operates at 4170 megacycles (center of band) and provides an almost flat gain of 38 db over a 50-megacycle band with a noise figure of approximately 0.6 db.

Bell Laboratories engineers have developed an extremely sensitive parametric amplifier which approaches the maser in sensitivity. Both will be used in experiments with Telstar, the Bell System's experimental communications satellite.

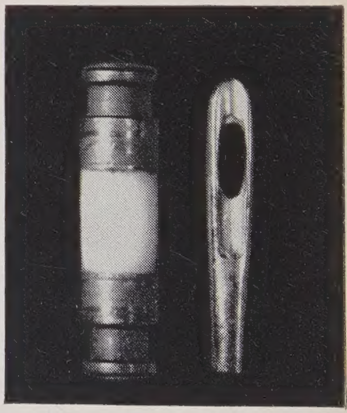
Heart of the parametric amplifier is a newly developed semiconductor diode with very low intrinsic noise. Previously, the sensitivity of such amplifiers at microwave frequencies was severely limited by the unwanted noise generated in their diodes. The new diode, no bigger than the eye-end of a needle, solved this problem.

Our engineers also devised new circuitry to stabilize precisely the output of the klystron (microwave generator) supplying power for the amplifier. To reduce further the intrinsic noise of the amplifier, they immersed the diode and its circuits in liquid nitrogen, utilizing a new cooling arrangement which economically maintains a low temperature for many days without attention.

The new amplifier fills a need in the communications field for a simple microwave amplifier of high sensitivity in applications for which the higher sensitivity of the maser does not justify its additional complication.



Close-up of the waveguide assembly, in which Bell Telephone Laboratories' newly developed diode is located.



Heart of amplifier—a hermetically sealed gallium arsenide diode—is compared with eye of average-sized sewing needle.

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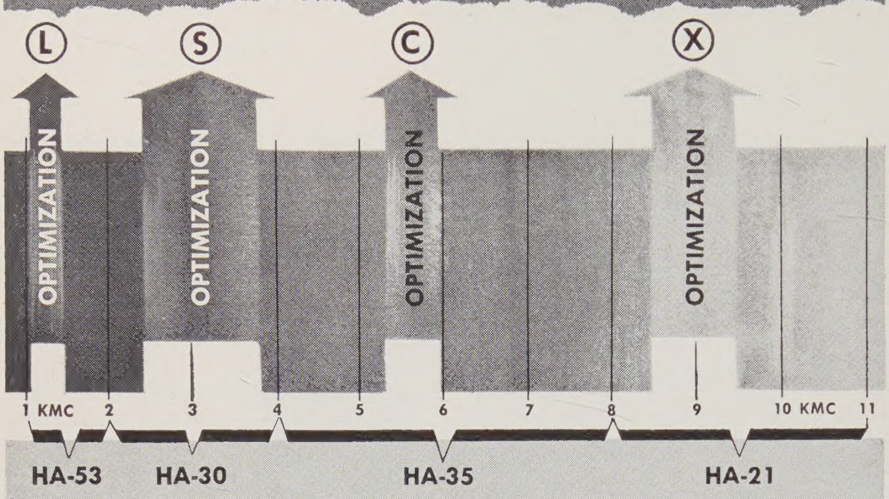
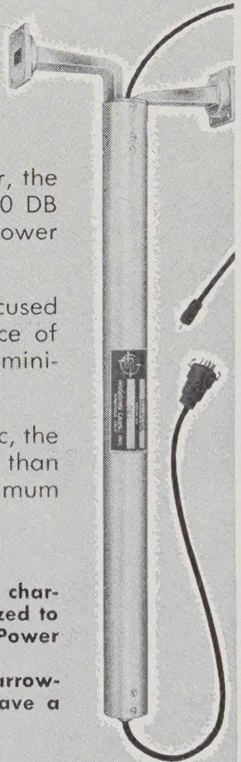


Ⓛ **1.1 - 1.4 kmc** The PPM focused type HA-53, normally operated from 1 - 2 kmc, when optimized is capable of greater than 35 DBM power output and 40 DB small-signal gain.

Ⓢ **2.4 - 3.8 kmc** Cataloged as a 2 - 4 kmc amplifier, the PPM focused HA-30 exhibits greater than 40 DB small-signal gain, with 33 DBM minimum power output over the narrow band.

Ⓒ **5.3 - 6.0 kmc** The HA-35, a 4 - 8 kmc solenoid focused amplifier, displays narrow-band performance of 32 DBM minimum power output, and 45 DB minimum small-signal gain.

Ⓧ **8.5 - 9.5 kmc** Normally operated from 8 - 11 kmc, the PPM focused type HA-21 is capable of more than 45 DB small-signal gain, and 31 DBM minimum power output when optimized.



Although the traveling wave tube is best known for its characteristics over a broad frequency range, it may be optimized to operate over a narrow band with outstanding results. Power output and small-signal gain are significantly increased.

If your system application requires a high-performance, narrow-band amplifier, contact Huggins Laboratories. We may have a TWT with the exact characteristics for your system.

HUGGINS LABORATORIES manufacture development engineering design research

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WRITE FOR SHORT FORM CATALOG

Meetings with Exhibits

● As a service both to Members and the industry, we will endeavor to record in this column each month those meetings of IRE, its sections and professional groups, which include exhibits.

Δ

August 21-24, 1962

Western Electronics Show and Conference (WESCON), Statler-Hilton Hotel & Memorial Sports Arena, Los Angeles, Calif.

Exhibits: Mr. Don Larson, WESCON, 1435 S. La Cienega Blvd., Los Angeles, Calif.

August 29-September 1, 1962

Second International Conference on Information Processing, Munich, Germany

Exhibits: Dr. Heinz Billing, Max Planck Institute, Munich, Germany

September 3-7, 1962

National Advanced Technology Management Conference, Opera House, Seattle World's Fair Grounds, Seattle, Wash.

Exhibits: Mr. Hugh Fairclough, 1624 22nd Avenue East, Seattle 2, Wash.

October 1-3, 1962

Eighth National Communications Symposium, Hotel Utica & Utica Municipal Auditorium, Utica, N.Y.

Exhibits: Mr. Charles Glaviano, 45 Meadow Dr., Rome, N.Y.

October 2-4, 1962

Seventh National Symposium on Space Electronics & Telemetry, Fontainebleau Hotel, Miami Beach, Fla.

Exhibits: Mr. Charles H. Doersam, Jr., Instruments for Industry, 101 New South Road, Hicksville, L.I., N.Y.

October 8-10, 1962

National Electronics Conference, McCormick Place, Chicago, Ill.

Exhibits: Mr. Rudy Napolitan, National Electronics Conference, 228 N. LaSalle St., Chicago, Ill.

October 15-18, 1962

Symposium on Space Phenomena & Measurement, Statler-Hilton Hotel, Detroit, Mich.

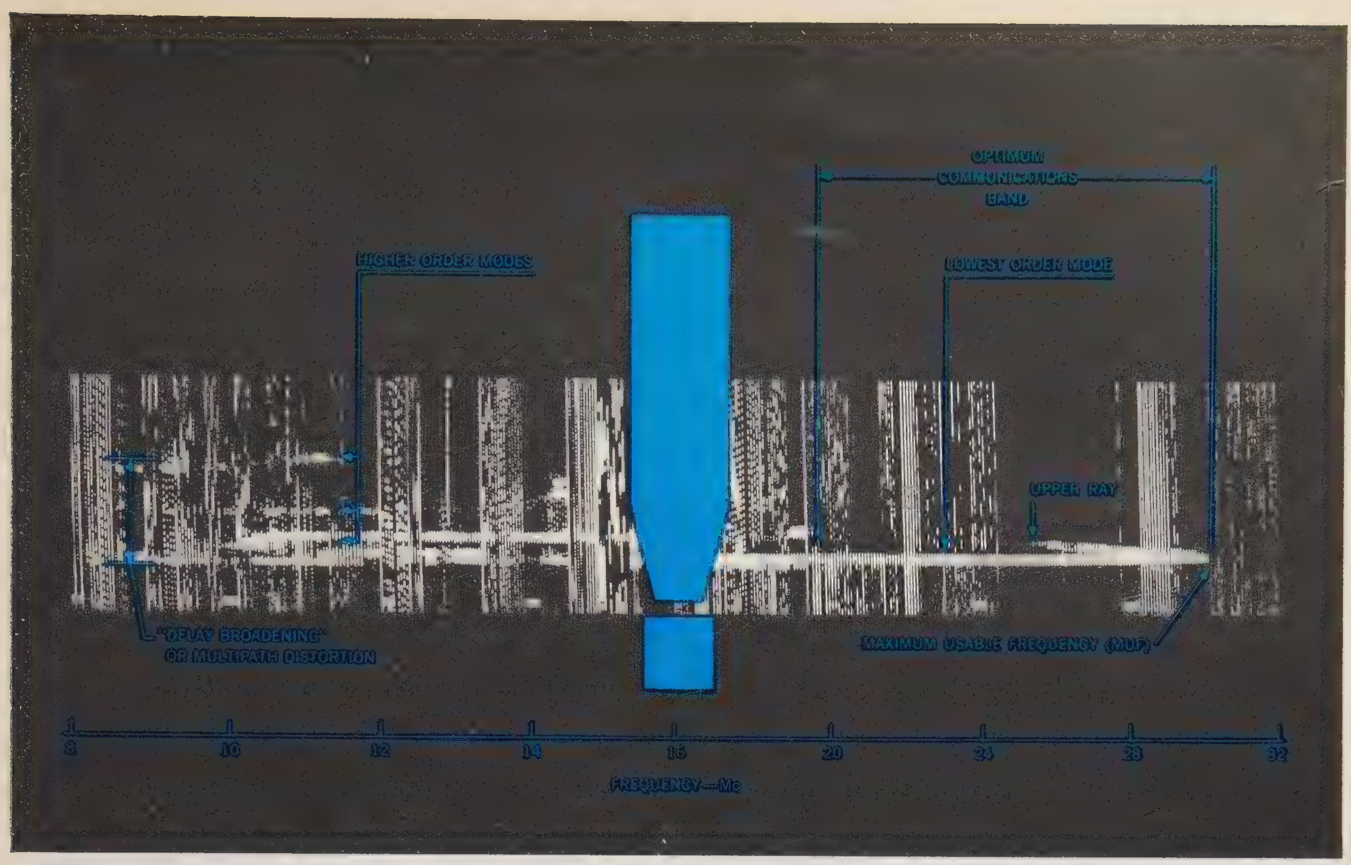
Exhibits: Mr. J. B. Bullock, University of Michigan, Ann Arbor, Mich.

November 1-2, 1962

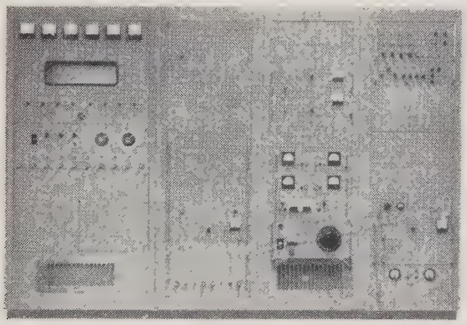
Sixth National Conference on Product Engineering and Production, Jack Tar Hotel, San Francisco, Calif.

Exhibits: Mr. W. Dale Fuller, Lockheed Missiles & Space Div., P.O. Box 504, Sunnyvale, Calif.

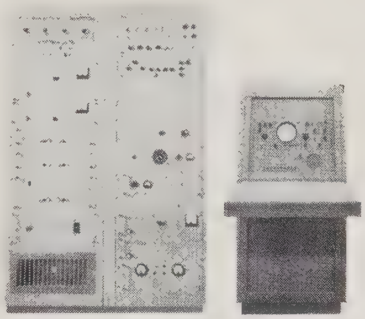
(Continued on page 10A)



h-f communicator—you need this picture!



Pathsounder transmitter system



Pathsounder receiver system

You get this accurate picture of actual point-to-point propagation conditions from Granger Associates' PATHSOUNDER* synchronized oblique ionosphere sounder system. The PATHSOUNDER* system is a high-speed step-frequency ionosphere sounder that scans up to 160 channels from 2 to 32 or 4 to 64 Mc at rates up to 50 frequencies per second. It gives the operator simultaneous data across the h-f band on relative signal strength, ionosphere mode stability, multipath effects, receiving site noise and interference, and optimum frequency transmission at any moment for point-to-point communications. The PATHSOUNDER* system is the first operational ionosphere sounder system to furnish this information. It is extremely reliable, versatile and flexible, with a wide range of sampling rates, frequency resolution and channel selection programs. Send for complete information from world's leading supplier of ionosphere sounder systems and h-f communication antennas.

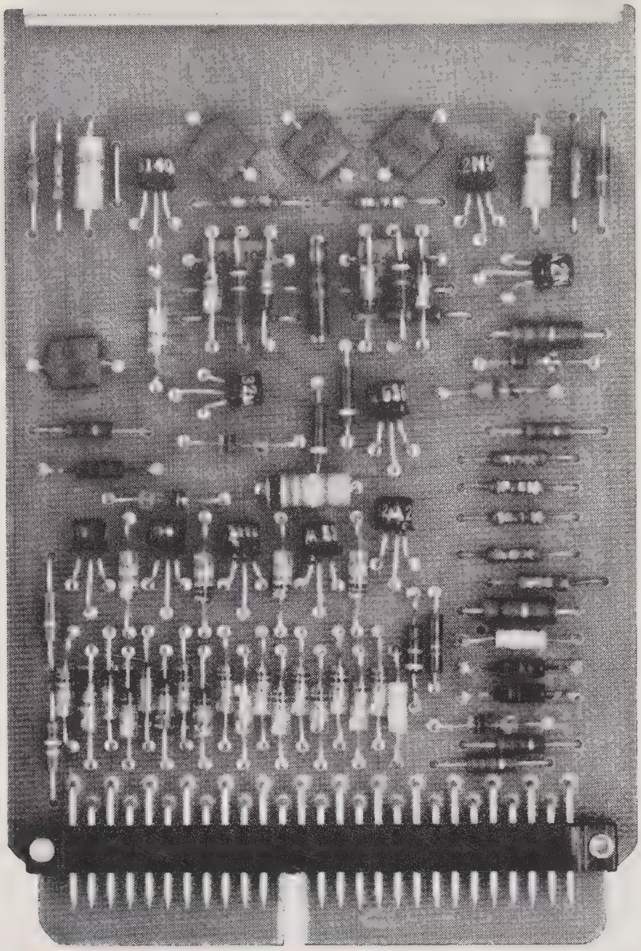
Granger
Associates

Opportunities for qualified antenna and communication engineers: contact personnel manager

*Trade Mark

Granger Associates / 974 Commercial Street, Palo Alto, California *DAvenport 1-4175 (area code 415)*

IN PRODUCTION



ACTUAL SIZE

20 mc across the board

20 mc 3C H-PACs are new. They come in a series — a full line. They complement the 16 mc H-PAC established in 1960. They fan out high (6 per side at 20 mc). From 0 to 20 mc a unique clock PAC performs comfortably. A 2000 bit capacity recirculating memory pac requires no temperature control. Wiring techniques are ordinary (do not require twisted pairs or shielded cabling). Mil versions are available. Versatile? Very.

COMPUTER CONTROL COMPANY, INC.

3C

EASTERN PLANT: 983 CONCORD STREET/FRAMINGHAM/MASS
WESTERN PLANT: 2251 BARRY AVENUE/LOS ANGELES 64/CAL

Meetings with Exhibits

(Continued from page 8A)

November 4-7, 1962

Fifteenth Annual Conference on Electronic Techniques in Medicine & Biology, Conrad Hilton Hotel, Chicago, Ill.

Exhibits: Professional Associates, Inc., 6520 Clayton Rd., Saint Louis 17, Mo.

November 5-7, 1962

NEREM (Northeast Research & Engineering Meeting), Commonwealth Armory & Somerset Hotel, Boston, Mass.

Exhibits: Mr. S. K. Gibson, Instruments of New England, 108 Greenwood Lane, Waltham 5, Mass.

November 12-15, 1962

Eighth Annual Conference on Magnetism & Magnetic Materials, Penn-Sheraton Hotel, Pittsburgh, Pa.

Exhibits: Mr. J. L. Whitlock, John Leslie Whitlock Associates, 253 Waples Mill Rd., Oakton, Va.

November 16-17, 1962

Communications Symposium, Queen Elizabeth Hotel, Montreal, P.Q., Canada

Exhibits: Mr. Arthur H. Gregory, Northern Electric Co., Ltd., 1600 Dorchester Blvd. W., Montreal, P.Q., Canada

November 19-20, 1962

MAECON (Mid-America Electronics Conference), Continental Hotel, Kansas City, Mo.

Exhibits: Dr. Arthur Goldsmith, Wilcox Electric Co., 1400 Chestnut, Kansas City 27, Mo.

December 4-6, 1962

Fall Joint Computer Conference, Sheraton Hotel, Philadelphia, Pa.

Exhibits: Mr. R. A. C. Lane, RCA Building 204-1, Camden 8, N.J.

December 6-7, 1962

13th National Conference on Vehicular Communications, Mayfair Hotel, Los Angeles, Calif.

Exhibits: Mr. Leslie M. Walker, Los Angeles County Dept. of Communications, 500 West Temple St., Los Angeles 12, Calif.

January 30-February 1, 1963

Fourth Winter Convention on Military Electronics, Ambassador Hotel, Los Angeles, Calif.

Exhibits: IRE Los Angeles Office, 1435 La Cienega Blvd., Los Angeles, Calif.

△

Note on Professional Group Meetings: Some of the Professional Groups conduct meetings at which there are exhibits. Working committeemen on these groups are asked to send advance data to this column for publicity information. You may address these notices to the Advertising Department and of course listings are free to IRE Professional Groups.

IN JUST 3 YEARS, METCOM HAS BECOME ONE OF THE LARGEST MANUFACTURERS OF REFLEX KLYSTRONS...

Progress happens fast at Metcom — now second in reflex klystron production among U.S. manufacturers . . . and first with such notable advances in the state of the art as the first voltage tuned reflex klystrons and the first frequency stabilized reflex klystrons — to name just two.

Today, we're working in highly advanced areas, including development for missiles and other space age applications. These advanced reflex klystrons feature low noise, high shock resistance and electrical and mechanical stability. And, their level of reliability is unsurpassed in the industry.

For reflex klystrons, come to Metcom.

Write today for our new catalog which includes specifications on over 500 tubes and components.

for better microwave tubes and devices . . . .

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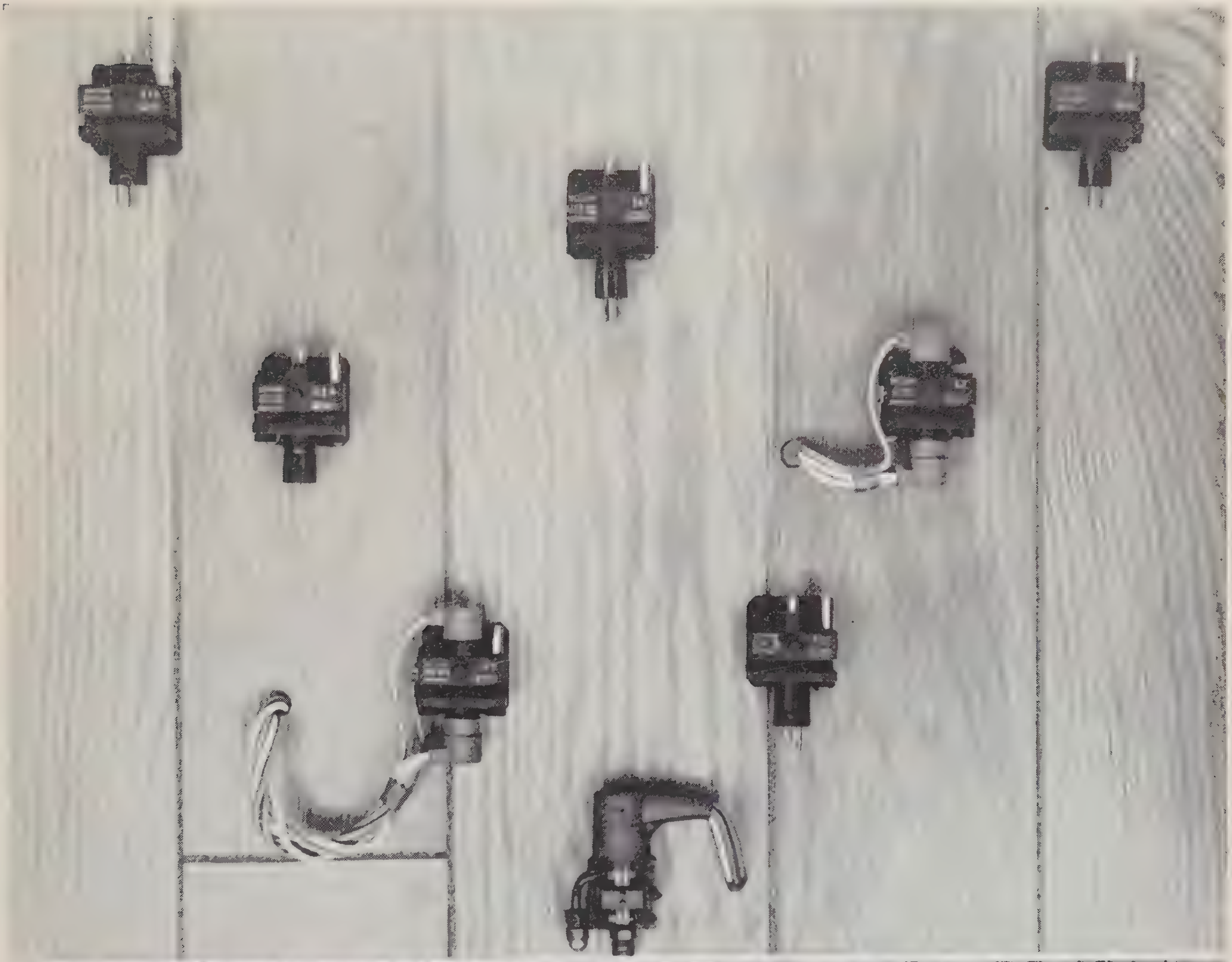
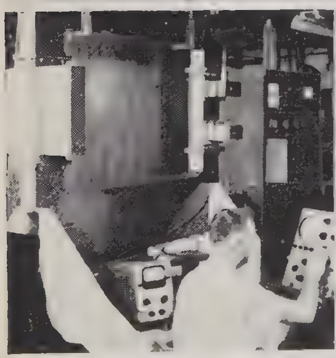
SALEM, MASSACHUSETTS

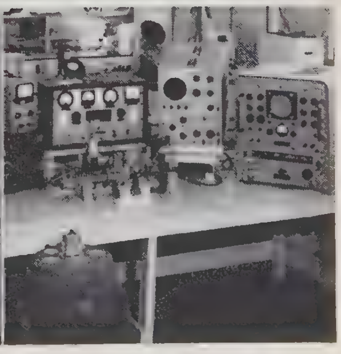




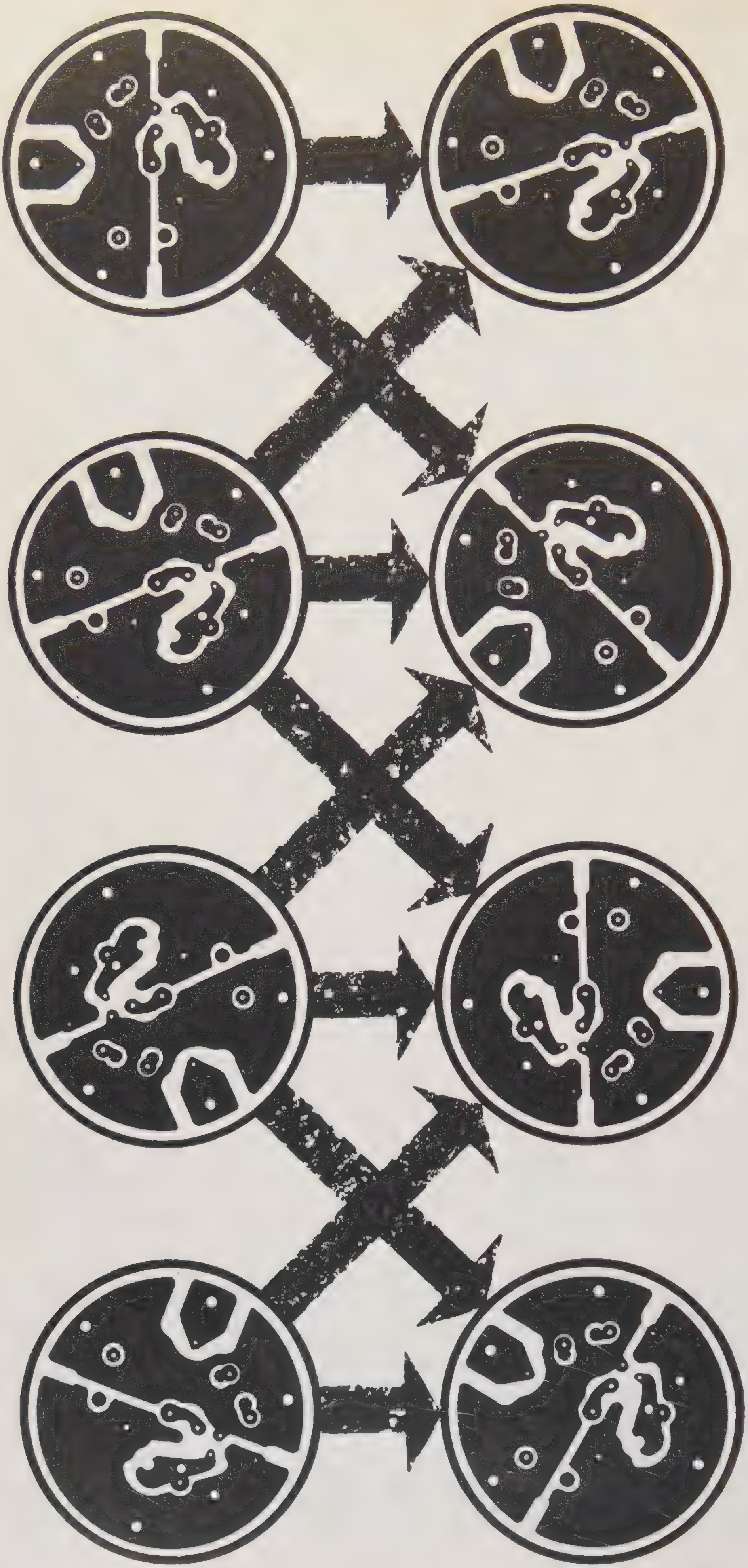
L-band high power simulator

Optical pyrometer checks oven temperature

Leak detector test area



Vibration test area



500 MEGACYCLE LOGIC SYSTEM, the first to take full advantage of the ultra high speed capabilities of the tunnel-diode, operates 50 times faster than present circuitry.

NEWS OF DEFENSE TECHNOLOGIES

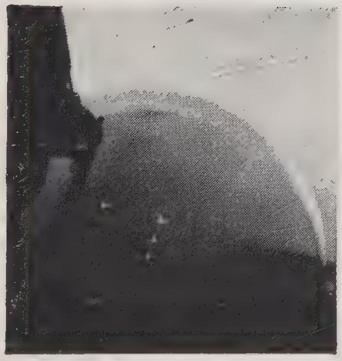
DATA

To perform effectively, modern defense systems must continuously evaluate every dynamic influence within their environments. Data must be speedily collected, rapidly compared with voluminous memories, and be presented in an organized, accurate and lucid display — *in real time.* All this to assist human judgment, that unassailable prime factor of military strategy.

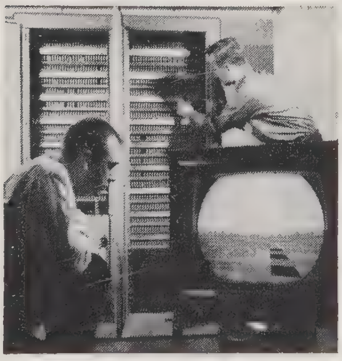
General Electric has played a major role in advancing the technologies of data utilization and display far beyond their early forms where manual computations of range and track data were accomplished at the plot board. In 1955, for example, General Electric introduced the AN/GPA-37 Radar Course Directing Group, the first mass produced equipment to perform semi-automatic tracking and automatic computation of the intercept problem. Later developments included the AN/FSA-12 Detector Tracking Group—the first equipment to demonstrate automatic detection and tracking of radar targets in all three dimensions—and the new Air Weapons Control System 412L, which provides the U. S. Air Force with the most modern aerospace management system available.

Today's accelerating progress in data technologies is evolving from leap-frog advances in logic and memory circuits and display techniques, and from an expanding scope of responsibility for the data processing and display functions. General Electric continues to make significant contributions to these technologies.

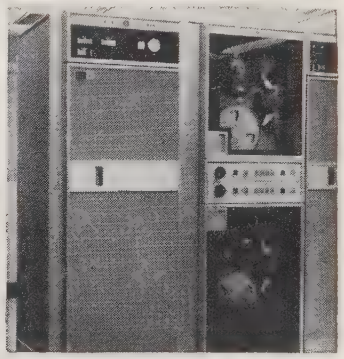
CRYOGENIC ASSOCIATIVE MEMORY enables computers to function like a human brain by instantaneously comparing and associating a new fact with all data in its memory.



THREE-DIMENSIONAL DISPLAY provides a realistic presentation of all spatial activity within its radar's range, in true perspective with scale references in all three dimensions.



CONTACT ANALOG DISPLAY for blind flying or flight simulation uses a digital computer to "paint" a moving TV picture of the ground analogous to the obscured real ground.



TDS-90 DATA SYSTEM transmits up to 62,500 characters a second via coaxial cable or microwave radio to link central processing equipment with remotely located computers.

Progress Is Our Most Important Product

GENERAL ELECTRIC

DEFENSE ELECTRONICS DIVISION

IRE News and Radio Notes

Current IRE Statistics

(As of April 30, 1962)

Membership—100,075
Sections*—111
Subsections*—33
Professional Groups*—29
Professional Group Chapters—299
Student Branches†—299

* See this issue for a list.
† See June, 1962 for a list.

Calendar of Coming Events and Author's Deadlines*

1962

- **July 17–18: Data Acquisition and Processing in Medicine and Biology, Whipple Aud., Strong Mem. Hosp., Rochester, N. Y.**
- Aug. 13–16: 7th Symposium on Ballistic Missile and Space Technology, United States Air Force Academy, Colorado Springs, Colo.
- **Aug. 14–17: Internat'l. Conf. on Precision Electromagnetic Measurements (former title: Conf. on Standards and Electronic Measurements), Nat'l. Bur. Standards, Boulder, Colo.**
- **Aug. 21–24: WESCON (Western Electronics Show and Conf.) Statler Hilton and Sports Arena, Los Angeles, Calif.**
- **Aug. 29–Sept. 1: 2nd Internat'l. Conf. on Information Processing, Munich, Germany.**
- **Sept. 3–7: Internat'l. Symp. on Information Theory, Brussels, Belgium.**
- **Sept. 3–7: Nat'l. Advanced Technology, Management Conf., World Fair Grounds, Opera House, Seattle, Wash.**
- Sept. 3–7: 45th Internat'l. Congress on Microwave Tubes, Kurhaus Hotel, Scheveningen, Netherlands.
- **Sept. 4–7: ACM Natl. Conf., Hotel Syracuse, Syracuse, N. Y.**
- **Sept. 13–14: 10th Annual Engineering Management Conf., Hotel Roosevelt, New Orleans, La.**
- **Sept. 13–14: Nat'l. Symp. on Engineering Writing and Speech, Mayflower Hotel, Washington, D. C.**
- **Sept. 19–20: 11th Annual Industrial Electronics Symp., Hotel Sheraton, Chicago, Ill.**
- **Sept. 28–29: 12th Annual Broadcast Symp., Willard Hotel, Washington, D. C.**
- **Oct. 1–3: 8th Nat'l. Communications Symp., Hotel Utica, Utica, N. Y.**
- **Oct. 2–4: Nat'l. Symp. on Space Elec. and Telemetry, Foutainebleau Hotel, Miami Beach, Fla.**
- Oct. 7–12: AIEE 1962 Fall General Meeting—3rd Ann. Symp. on Switching, Circuit Theory and Logical Design, Chicago, Ill.

* DL = Deadline for submitting abstracts.

(*Continued on page 15A*)

DR. A. N. GOLDSMITH ELECTED RCA HONORARY VICE PRESIDENT

The Board of Directors of the Radio Corporation of America has elected Dr. Alfred N. Goldsmith, noted scientist, engineer and inventor, an Honorary Vice President.

Dr. Goldsmith, who has made many inventions in the fields of radio, motion pictures and television, was Director of Research and later Vice President of RCA from 1919 to 1933, when he resigned to become an independent consultant. He has since served as Senior Technical Consultant to RCA.

Born in New York City in 1888, Dr. Goldsmith began his career as an instructor at the College of the City of New York in 1907, the same year he received his Bachelor of Science degree from that college. He remained with CCNY until 1919 and, in the meantime, obtained his Doctorate of Philosophy from Columbia University, New York, N. Y., in 1911. CCNY appointed him Associated Professor of Electrical Engineering for life. He was granted an honorary Doctor of Science degree by Lawrence College in 1935.

(*Above*) Dr. Alfred N. Goldsmith, recently elected Honorary Vice President of the Radio Corporation of America.

He was consulting engineer for General Electric Company from 1915 to 1917, and Director of Research for Marconi Wireless Telegraph Company of America from 1917 to 1919. That year he joined the Radio Corporation of America as Director of Research.

In 1920 his work made possible the first commercial radio with only two control knobs and a built-in speaker. He also made vital contributions to the development of the first color television tube to find commercial use.

Dr. Goldsmith, who is the author of several books, is a Co-founder, Fellow, and Life Member of the IRE. He was President in 1928 and, with the exception of one year, has served as Editor or Editor Emeritus from 1912 to the present. He held the post of Secretary of the IRE from 1918 to 1927 and has served on the Board of Directors ever since the IRE was founded in 1912. Among his many honors, he was the recipient of the IRE Medal of Honor in 1941, and the IRE Founders Award in 1954. In March, 1962, he was honored with a scroll of tribute by the IRE at its Golden Anniversary celebration.

Dr. Goldsmith was elected President of the Society of Motion Picture and Television Engineers in 1932, and has been chairman of several sectional committees of the American Standards Association. He is an honorary member of the Radio Society of Great Britain, the International Committee of Radio Telegraphy (France), the Academy of Motion Picture Arts and Sciences, and the Institution of Radio Engineers (Australia). He is also an Eminent Member of Eta Kappa Nu and is a member of the New York Medico-Surgical Society. In addition, Dr. Goldsmith is a Fellow of the American Institute of Electrical Engineers, the American Physical Society, the American Association for the Advancement of Science, the Acoustical Society of America, the Optical Society of America, and the International College of Surgeons.

CALL FOR PAPERS IRE NEW ENERGY SOURCES ISSUE

A special issue of the PROCEEDINGS OF THE IRE on New Energy Sources is planned for publication during the spring of 1963. The emphasis will be on new scientific and technological developments rather than system design or system performance. Tentatively, it has been decided to look for papers in the following areas: a) Thermoelectricity, b) Plasma Physics (Plasma Diode and MHD Generators), c) Photovoltaic Conversion, d) Fuel Cells, and e) New Approaches to Power Production.

A brief description or suggested titles of possible contributions should be submitted to: W. H. Clingman, *Editor*, IRE New Energy Sources Issue, Texas Instruments Inc., P.O. Box 5474, Dallas 22, Tex. In order to meet the desired publication schedule manuscripts should be available by December 1, 1962. Three copies of the paper, including one set of reproducible illustrations and a photograph and biography of each author should be submitted. Inquiries may also be directed to: E. K. Gannett, *Managing Editor*, PROCEEDINGS OF THE IRE, Institute of Radio Engineers, 1 East 79th St., New York 21, N. Y.

PROFESSIONAL GROUP NEWS

At its meeting on May 23, 1962, the IRE Executive Committee approved the following new Chapters: PG on **Communications Systems**—Denver Chapter; PG on **Education**—Salt Lake City Chapter; PG on **Engineering, Writing and Speech**—Detroit Chapter; PG on **Military Electronics**—South Carolina Chapter.

Call for Papers

1963 IRE INTERNATIONAL CONVENTION

March 25–28, 1963

Waldorf-Astoria Hotel and the New York Coliseum, New York, N. Y.

Prospective authors are requested to submit all of the following information by the

Deadline Date of October 19, 1962

1. 100-word abstract *in triplicate*, title of paper, name and address
2. 500-word summary *in triplicate*, title of paper, name and address
3. Indicate the technical field in which your paper should be classified:

Aerospace & Navigational Electronics
Antennas & Propagation
Audio
Automatic Control
Bio-Medical Electronics
Broadcast & Television Receivers
Broadcasting
Circuit Theory
Communications Systems
Component Parts
Education
Electron Devices
Electronic Computers
Engineering Management
Engineering Writing & Speech
Geoscience Electronics
Human Factors in Electronics
Industrial Electronics
Information Theory
Instrumentation
Microwave Theory & Techniques
Military Electronics
Nuclear Science
Product Engineering & Production
Radio Frequency Interference
Reliability & Quality Control
Space Electronics & Telemetry
Ultrasonics Engineering
Vehicular Communications

Note: Only original papers, not published or presented prior to the 1962 IRE International Convention, will be considered. *Any necessary military or company clearance of papers must be granted prior to submission.*

Address all material to: Dr. Donald B. Sinclair, Chairman
1962 Technical Program Committee
The Institute of Radio Engineers, Inc.
1 East 79 Street, New York 21, N. Y.

CALL FOR PAPERS SPACE PHENOMENA AND MEASUREMENT SYMPOSIUM

The International Symposium on Space Phenomena and Measurement will be held at the Statler-Hilton Hotel, Detroit, Mich., Oct. 15–18, 1962. The symposium will concentrate on, but not be limited to, a discussion of fundamental and applied research on space environment, including trapped and cosmic radiation, magnetic fields, radiation effects on materials, and instruments for space exploration. In addition, it will report recent advances on nucleonic instruments and controls, space and laboratory diagnostics; these advances not necessarily applying to space research.

Three days of technical sessions are scheduled with single morning and afternoon sessions on October 16 featuring invited papers on highlight topics. Two parallel sessions are scheduled for both the morning and afternoons on October 17 and 18, one session on the highlight topic in parallel with a session on traditional PGNS topics. Topics to be included in the highlight sessions are: 1) Recent Satellite Research on Energetic Particles and Magnetic Fields, 2) Recent Results in Astronomy and Interplanetary Plasma Physics Research, 3) Effect of Space Radiation Environment on Semiconductor Components, 4) Scientific Instrumentation and Measurement for Space Exploration, and 5) Selected Topics in Space Measurements. Examples of the topics to be included in the general sessions are: 1) Dynamic Analysis and Control, 2) Nuclear Instrumentation, 3) Plasma Diagnostics, and 4) Nuclear Test Detection, Including Underground, Atmospheric and Space Bursts.

Dr. Homer Newell, Director, NASA Office of Space Sciences, will give the keynote address at the highlight luncheon October 16.

Papers for presentation at this symposium are being accepted. Subject matter for the papers may be related to either the highlight or the general topics. A rough draft of each paper and a 500-word abstract should be submitted to the Papers Chairman by July 1, 1962. The length of each paper should be approximately 25 minutes. Persons interested in submitting papers for presentation should send the rough draft and abstract to: Michael Ihnat, AVCO Corp., 201 Lowell St., Wilmington, Mass.

INDUSTRIAL ELECTRONICS SYMPOSIUM SCHEDULED

The Eleventh Annual Industrial Electronics Symposium will be held at the Hotel Sheraton, Chicago, Ill., Sept. 19 and 20, 1962. This symposium is jointly sponsored by the IRE, AIEE and the ISA.

Papers, presented in four sessions, will be concerned with industrial electronic advances in the areas of Electro-Optic, Electro-Magnetic, Electro-Mechanical, and Electro-Chemical Techniques.

Calendar of Coming Events and Author's Deadlines*

(Continued from page 14A)

Oct. 8–10: Natl'l. Elec. Conf., McCormick Pl., Chicago, Ill.

Oct. 12–13: 7th Annual North Carolina Section Symp., Greensboro Coliseum, Greensboro, N. C.

Oct. 15–17: URSI-IRE Fall Meeting, Ottawa, Canada.

Oct. 15–18: Symp. on Space Phenomena and Measurement, Statler-Hilton, Detroit, Mich.

Oct. 22–24: ECCANE (East Coast Conf. on Aerospace and Navigational Elec.) Emerson Hotel, Baltimore, Md.

Oct. 25–27: Electron Devices Meeting, Sheraton Park Hotel, Wash., D. C.

Oct. 30–31: Conf. on Engrg. Techniques in Missile and Spaceborne Computers, Disneyland Hotel, Anaheim, Calif.

Nov. 1–2: 6th Nat'l. Conf. on Product Engr. and Production, Jack Tar Hotel, San Francisco, Calif.

Nov. 4–7: 15th Annual Conf. on Elec. Tech. in Medicine and Biology, Conrad Hilton Hotel, Chicago, Ill.

Nov. 5–7: NEREM (Northeast Res. and Engr. Meeting, Commonwealth Armory, Somerset Hotel, Boston, Mass.

Nov. 12–14: Radio Fall Meeting, King Edward Hotel, Toronto, Ont., Canada.

Nov. 12–15: 8th Annual Conf. on Magnetism and Magnetic Mat., Penn-Sheraton, Pittsburgh, Pa.

Nov. 16–17: Communications Symposium, Queen Eliz. Hotel, Montreal, P.Q., Canada.

Nov. 19–20: MAECON (Mid-America Electronics Conf.), Continental Hotel, Kansas City, Mo.

Nov. 28–30: 1962 Ultrasonics Symp., Columbia Univ., New York, N. Y.

Nov. 29–30: 1962 Ultrasonics Symp., New York City. (DL*: August 13, 1962, for 200-word abstracts.)

Dec. 4–6: FJCC (Fall Joint Computer Conf.), Sheraton Hotel, Philadelphia, Pa.

Dec. 6–7: 13th Nat'l. Conf. on Vehicular Communications, Disneyland Hotel, Anaheim, Calif.

1963

Jan. 22–24: 9th Nat'l. Symp. on Reliability and Quality Control, Sheraton Palace Hotel, San Francisco, Calif.

Jan. 30–Feb. 1: 4th Winter Convention on Military Electronics, Ambassador Hotel, Los Angeles, Calif.

Feb. 11–15: 3rd Internat'l. Symp. on Quantum Electronics, UNESCO Bldg., Paris, France. (DL*: Oct. 1, 1962, Madame Cauchy, Secretaire 3ème Congress d'Electronique Quantique, 7 rue de Madrid, Paris 8ème, France.)

Feb. 20–22: Internat'l. Solid State Circuits Conf., Sheraton Hotel and Univ. of Pa., Phila., Pa.

Mar. 25–28: IRE International Convention, Coliseum and Waldorf Astoria Hotel, New York, N. Y.

Apr. 17–19: Southwestern IRE Conf. and Elec. Show, Dallas Memorial Auditorium, Dallas, Tex.

* DL = Deadline for submitting abstracts.

List of IRE Conference Publications Available

IRE Headquarters has compiled a list of all available publications which have resulted from conferences sponsored or co-sponsored by the IRE. The list, called "Miscellaneous IRE Publications Available," indicates the name and dates of each conference, the price, and how to order. Copies of the list are available upon request from IRE Headquarters, 1 East 79th Street, New York 21, N. Y.

1962 Fall URSI–IRE Meeting And Call for Papers

The 1962 Fall International Scientific Radio Union and IRE Meeting will be held in Ottawa, Ontario, Canada, on October 15–17, 1962. This meeting is jointly sponsored by the URSI National Committees of the United States and Canada and by the IRE Professional Groups on Antennas and Propagation, Circuit Theory, Information Theory, Instrumentation, Microwave Theory and Techniques, and Geoscience Electronics.

There will be seven commissions included in the meeting. These are: 1) Radio Measurement Methods and Standards; 2) Radio Propagation in Non-Ionized Media; 3) Ionospheric Radio; 4) Magnetospheric Radio; 5) Radio and Radar Astronomy; 6) Radio Waves and Transmission of Information; and 7) Radio Electronics (sponsored by Canadian Commission only).

The deadline for submission of two hundred word abstracts is August 15, 1962. Abstracts should be mailed in duplicate to: Dr. J. H. Chapman, URSI Program Chairman, Defence Research Telecommunications Establishment, Shirley Bay, Ottawa, Ontario, Canada. Authors should indicate which commission papers are intended for, but they should not be sent to the Commission Chairman.

Final Call for Papers Electron Devices Meeting

The 1962 Electron Devices Meeting, sponsored by the IRE Professional Group on Electron Devices, will be held at the Sheraton Park Hotel, Washington, D. C., Oct. 25–27, 1962.

In order for a paper to be considered for presentation at this meeting, an original and four copies of an informative abstract of approximately 200 words must be received by August 1, 1962. The abstracts should be as factual as possible and will be used by the Committee in deciding which papers will be accepted.

Papers should deal with material of an applied or development nature in the broad field of electron devices. Consistent with the divisional structure of the Professional Group, papers are invited in the fields of Integrated Electronic Devices and Energy Sources, in addition to the fields of Solid-State Devices and Electron Tubes. They should be concerned primarily with the device itself, or important new device technology, rather than with its application or circuitry, except insofar as circuitry is built into the device.

Abstracts should be sent to: J. Earl Thomas, Jr., IBM Components Lab., Bldg. 701, Dept. 677, Poughkeepsie, N. Y.

Instrument Symposium To Be Held in October

The Twelfth Annual Instrument Symposium and Research Equipment Exhibit will be held at the National Institutes of Health, Bethesda, Md., Oct. 8–12, 1962.

The Chairman for the Symposium on Recent Developments in Research Methods and Instrumentation is: Dr. E. R. Lippincott, Department of Chemistry, University of Maryland, College Park, Md. The primary topics for discussion on the scientific program include: 1) Thin Film and Gas Chromatography, 2) Ion Exchange Techniques, 3) Nuclear Magnetic Resonance, 4) Optical Masers, 5) Vacuum Ultraviolet, 6) X-ray Microscopy, 7) Automation in Chemical and Biochemical Research, 8) Physiological Monitoring, and 9) X-ray Diffraction Studies of Proteins.

Examples of the latest types of research equipment will be exhibited by instrument manufacturers. The Chairman for the Research Equipment Exhibit is: Louis Heiss, American Instrument Co., Inc., 8030 Georgia Ave., Silver Spring, Md.

E. F. Seaman Retires From the U.S. Navy Department

Ellsworth F. Seaman has recently retired from the U. S. Navy Department, Bureau of Ships. He joined the Bureau of Engineering, now Bureau of Ships, in 1931 and has been assigned to important and responsible positions in the fields of engineering and management including Department of Navy management responsibility for the Armed Services Electro Standards Agency.

E. F. Seaman

Mr. Seaman is a registered professional engineer and has been a member of American Institute of Electrical Engineers for almost twenty years. He is a member of the American Society for Testing Materials and has been active over a period of years especially in the field of environmental testing. His work as Chairman of the International Electrotechnical Commission, Committee TC 50, covering environmental test method standards, has taken him into the international field. In the capacity as Chairman of this committee he has traveled extensively in this country and abroad.

Mr. Seaman will continue his career as a consultant in engineering and management and related fields, specializing in standardization and environmental engineering.

Ballistic Missile And Space Technology Symposium Schedule Changed

The Seventh Symposium on Ballistic Missile and Space Technology, sponsored by United States Air Force and Aerospace Corp., will be held at the United States Air Force Academy, Colorado Springs, Colo., Aug. 13–16, 1962, instead of at the Statler Hilton Hotel, Los Angeles, Calif., beginning Aug. 27.

Because of the heavy tourist trade in Colorado Springs during the summer months, special arrangements have been made to accommodate Symposium attendees. An office will be established in Colorado Springs for handling hotel and motel reservations. All reservations for the Symposium must be handled through that office, in order to avoid confusion and possible disappointment.

Engineering Management Conference Announced

The Tenth Annual Engineering Management Conference (jointly sponsored by the AIChE, AICE, AIEE, AIIE, AIME, ASCE, ASME and IRE) will be held at the Roosevelt Hotel, New Orleans, La., Sept. 13–14, 1962.

These annual conferences are designed to accomplish the following objectives: 1) To provide managers of engineering (and technical work in general) with a national forum through which to explore latest advances in the field; 2) to help in the self-education of those starting or aspiring to position as managers of engineering and technical work; 3) to explore changing conditions which affect the managing of engineering and other highly specialized technical work; and 4) to review educational implications of rapidly changing technical requirements from the point of view of undergraduate and graduate schools, individual self-development efforts of professional workers, and in-service Company programs.

The conference sessions will include: 1) The Challenge of the Future, 2) Engineering Education, 3) Managerial Contribution to Engineering Work, and 4) Contributions by Engineers to Managerial Work.

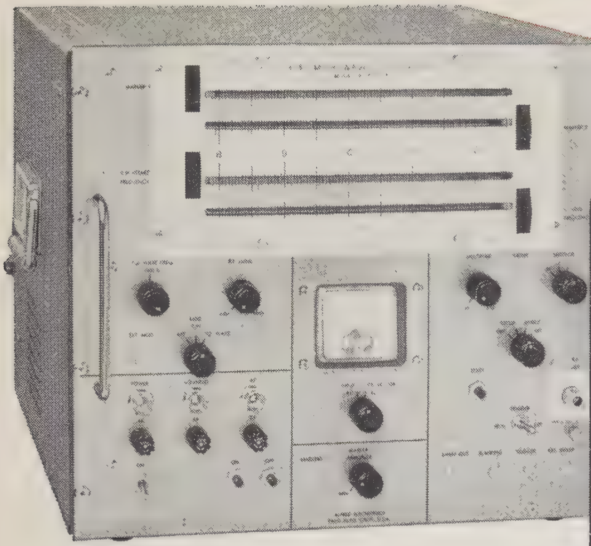
Call for Papers Ultrasonics Symposium

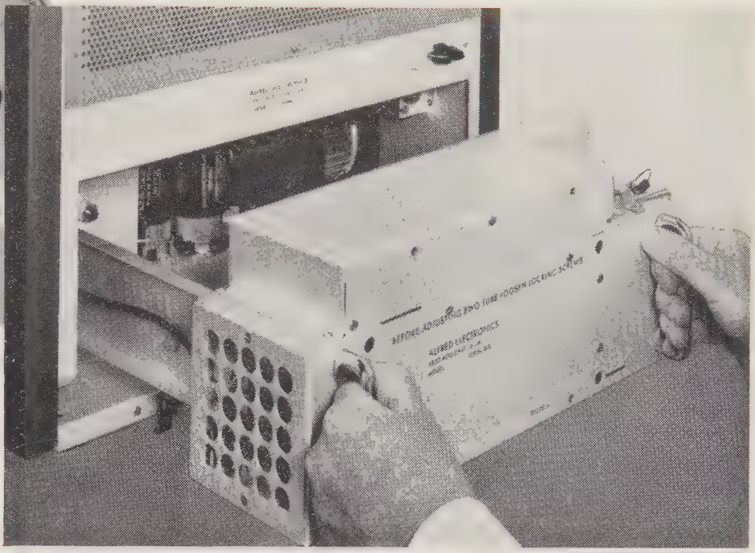
The 1962 Ultrasonics Symposium, under PGUE sponsorship, will be held at Columbia University, New York, N. Y., Nov. 28–30, 1962. The Symposium Committee General Chairman is J. E. May, Jr.

Contributed papers are sought in any of the various specialties of ultrasonics. At this meeting, particular emphasis will be given to microwave ultrasonics and a program of invited papers has been planned to give comprehensive coverage of this field.

Three copies of a 200-word abstract should be submitted prior to August 13, 1962 to: R. N. Thurston, Technical Program Chairman, Bell Telephone Labs., Murray Hill, N. J.

WHY BUY SIX SWEEPERS to cover 1 to 26.5 Gc?





Plug-in Generator Head slides simply and quickly into Alfred's Model 605 General Frequency Oscillator.

ALFRED 605 saves time, plug-in heads save money. Buy one Model 605 and **only** the plug-in Generator Heads you need now. Extend frequency range with additional Heads when your requirements change. The 605 with six plug-ins provides electronically swept or single frequency coverage from 1 to 26.5 Gc. Sweep rate adjustable from 100 cps to 0.01 cps permits either oscilloscope or recorder display of broadband microwave component characteristics.

Your Model 605 is **never** obsolete; greater coverage is possible with new Heads as they become available. Special frequency requirements are covered with intermediate range Heads (some are listed below).

Heads Easily Installed—Heads are pre-calibrated—no adjustment needed—and can be changed in 3 minutes. Any Head can be used with any Model 605.

Replaces Signal Generators—As single frequency signal sources ALFRED Microwave Oscillators are as stable as mechanically tuned signal generators.

Field Proven Performance—Over 2 years in production and over 200 units in service.

SPECIFICATIONS

SWEEP WIDTH Continuously adjustable from 0 to any part of the entire frequency range with direct calibrated dial.

SELECTOR Recurrent Sweep, Single Sweep, CW, and External.

CONTROL Single Sweep triggered by panel button, external positive going 20 v signal or internal line frequency signal.

TIME 100 to 0.01 second.

EXTERNAL SWEEP 200 v gives full sweep. DC to approx. 10 Kc response.

FREQUENCY MARKERS Two markers continuously adjustable over entire frequency range.

INTERNAL AM Square wave, 800 to 1200 cps.

EXTERNAL AM 25 v for 100% control. DC to 1 Mc response.

PRICE Model 605: $1,750 fob factory.

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GENERATOR HEADS FOR MODEL 605

A Generator Head consists of voltage tuned backward wave oscillator and focusing magnet arranged for convenient insertion into Model 605. When installed the Heads will perform to following specifications:

Generator Head Model Number	GA102	GA103	GA204	GA408	GB6012	GB7013	GB7013A	GB10015	GB12018	GC15022	GC18026
Frequency Range Gc	1 to 2	1.4 to 2.5	2 to 4	4 to 8	6.5 to 11.5	8 to 12.4	8.2 to 12.4	10 to 15.5	12.4 to 18	15 to 22	18 to 26.5
Power Output—minimum mw	10	10	10	10	10	10	10	10	10	5	3
Residual FM percent peak	0.003	0.003	0.0025	0.002	0.002	0.0015	0.0015	0.001	0.001	0.001	0.001
Drift % of max. freq/hr.	±0.025	±0.02	±0.02	±0.01	±0.01	±0.01	±0.01	±0.01	±0.01	±0.01	±0.01
Price of Generator Heads	$1690	$1790	$1690	$1590	$1590	$1590	$1650	$1940	$1990	$2650	$2950

CALL FOR PAPERS 1963 SOLID-STATE CIRCUITS CONFERENCE

The 1963 International Solid-State Circuits Conference will be held in Philadelphia, Pa. at the University of Pennsylvania and the Sheraton Hotel, Feb. 20–22, 1963.

The conference, which has become a recognized international platform for the announcement of new circuits and applications of solid-state devices, will again be jointly sponsored by the IRE, and the University of Pennsylvania. Papers in the following or related fields are invited: 1) Solid-state microwave amplification, oscillation and conversion, 2) Solid-state data storage and logic, 3) Significant circuit developments, providing improvements in bandwidth, gain, noise figure, stability, or reliability, 4) Solid-state devices performing an integrated circuit function, 5) Micro-circuit techniques for improved system performance and reliability, 6) New devices and device characterization, 7) Solid-state techniques for adaptive systems, 8) Quantum electronics; maser and optical maser techniques, 9) Cryogenics, and 10) Optoelectronics.

Authors are requested to submit both a 300–500-word summary of the paper and a 35-word abstract. The summary should highlight the nature of the contribution to the art and include theoretical and experimental results when available; the inclusion of key illustrations is encouraged.

Summaries must be submitted in single-side, black-on-white, double-spaced typewritten form suitable for immediate reproduction. The author's name, affiliation, address and telephone contact must appear on the first page, and the author's name and abbreviated paper title on each subsequent page. The 35-word abstract should be typed on a separate sheet.

Summary and abstract should be forwarded on or before Nov. 1, 1962, to the Program Committee Secretary: A. K. Rapp, Philco Scientific Lab., Blue Bell, Pa.

Chairman of the 1963 conference is F. H. Blecher, Bell Telephone Labs., Inc., N. Andover, Mass.

CALL FOR PAPERS TRI-SERVICE CONFERENCE

The Eight Tri-Service Conference on Electromagnetic Compatibility will be held in Chicago, Ill., Oct. 30–Nov. 1, 1962, and will be sponsored by the U. S. Army, Navy, and Air Force in cooperation with the IRE Professional Group on Radio Frequency Interference. The theme of the Conference is radio interference reduction and electromagnetic compatibility.

Technical papers will cover interference prediction, equipment design techniques, instrumentation, measurement techniques, and interference reduction measures. An abstract of approximately 150 words or a copy of the paper should be submitted by August 1, 1962 to: J. E. McManus, Conference Chairman, Armour Research Foundation, Illinois Institute of Technology, 10 West 35th St., Chicago 16, Ill.

CALL FOR PAPERS 1963 INTERMAG CONFERENCE

The International Conference on Nonlinear Magnetics will be held at the Shoreham Hotel, Washington, D.C. April 17–19, 1963. The INTERMAG Conference is sponsored jointly by IRE-AIEE.

The theme of next year's conference will emphasize the theory and application of advanced nonlinear magnetic devices in the fields of computation and control. Leading foreign authorities, as well as U. S. experts, will present the most recent developments in computer logic and memories, such as thin magnetic films; power devices, such as magnetic amplifiers; combination of nonlinear magnetics with semi-conductors, such as silicon controlled rectifiers; recording and instrumentation. Some of these subjects will also be covered by state of the art presentations.

Abstracts of about 200 words should be submitted as early as possible, but not later than November 5, 1962 to: Dr. J. J. Suozzi, Technical Program Chairman, Bell Telephone Labs., Inc., Whippany, N. J.

NATIONAL PGVC CONFERENCE CALL FOR PAPERS

The 13th National Conference of the IRE Professional Group on Vehicular Communications will be held at the Disneyland Hotel, Anaheim, Calif., Dec. 6–7, 1962. Papers on subjects covering the vehicular systems and equipment designs are invited. Discussions on new or unusual system techniques, applications of new types of components or related circuitry, interference reduction or spectrum utilization are invited. Manufacturers and users are urged to take advantage of this opportunity to share their experiences in this rapidly expanding communications field. Topics covered may include land vehicular, personal signaling, solid state applications to communications, VHF maritime and air-ground communications.

An abstract of 500 words is required for review by the Papers Committee by August 15, 1962. These should be mailed to: William J. Weisz, Motorola, Inc., 4501 W. Augusta Blvd., Chicago 51, Ill. Authors will be notified by September 15, 1962.

PGPEP CONFERENCE SET FOR NOVEMBER

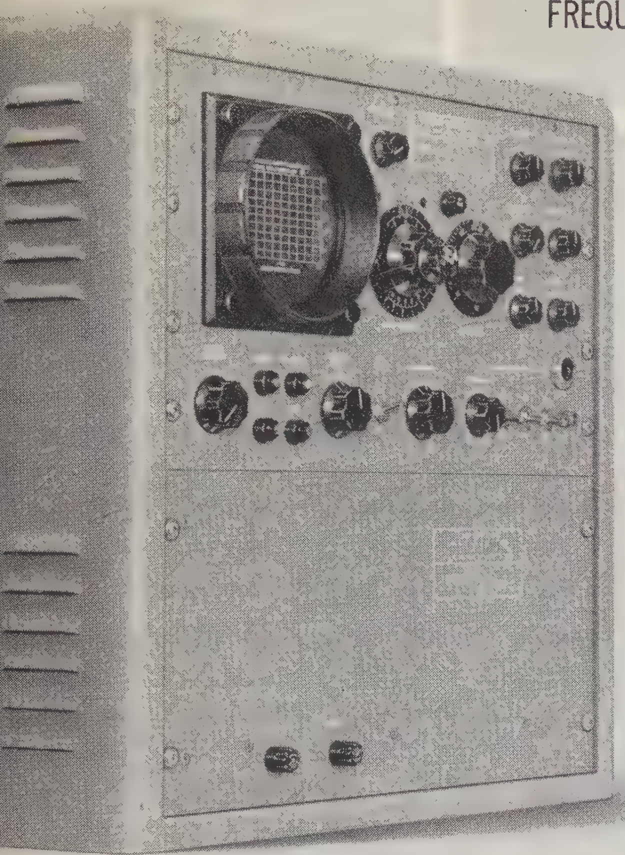
The San Francisco chapter of the IRE Professional Group on Product Engineering and Production will hold the Sixth National Conference at the Jack Tar Hotel, San Francisco, Calif., Nov. 1 and 2, 1962. The theme for the conference is "Product Engineering for the Sixties."

The program for the conference will cover joining Techniques, Process Equipment, Production, and Circuit Packaging. Program chairman is: George Reyling, 30 Toro Court, Portola Valley, Menlo Park P.O., Calif. The conference will also feature exhibits of production equipment used in electronic testing and manufacturing. Chairman for the exhibits committee is: Dale W. Fuller, 1420 Hamilton, Palo Alto, Calif. General chairman for the conference is Art Kromer of Varian Associates.

1kc to 25mc
FREQUENCY RANGE

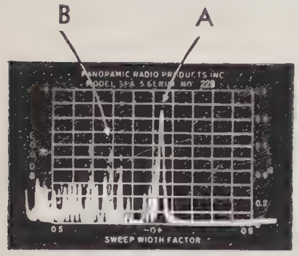
up to 3mc
SWEEP WIDTH

2μv
USABLE SENSITIVITY

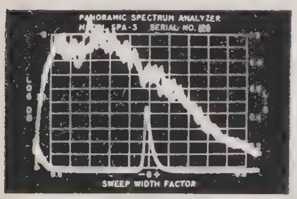


MORE CAPABILITIES for MORE APPLICATIONS

PANORAMIC MODEL SPA-3/25 SPECTRUM ANALYZER



Analysis of multiplexed voice communications circuit pinpoints high channel level (A) due to "singing" or oscillations. Adjacent channels at 4 kc intervals, some voice modulated, are also seen. Voice peaks (B) show up clearly. 40 db log scale.



Noise spectrum analysis using internal video smoothing filter displays average noise level versus frequency in easily appreciated form. Internal marker pips are 500 kc apart.

HIGHLIGHT SPECIFICATIONS

Frequency Range 1 kc—25 mc (usable to 200 cps) (SPA-3 to 15 mc)

Sweep Width Adjustable, calibrated from 0 to 3 mc

Center Frequency Adjustable, calibrated from 0 to 23.5 mc.

Markers Crystal controlled, 500 kc and harmonics to 25 mc.

Resolution I-F bandwidth adjustable, 200 cps thru 20 kc

Sweep Rate 1 to 60 sweep/sec. continuously adjustable Sweep operated synchronized to power line, or non-synchronized.

Amplitude Scales Linear, 40 db Log and Power

Sensitivity 20 μv to 2 v full scale. Min. discernible level = 2 μv

Attenuator 100 db calibrated

Response Flatness ±15% or ±1.5 db up to 23.5 mc

Input Impedence 72 ohms. (50 ohms optional. High impedence probe PRB-1, optional)

dependable CERTIFIED SPECIFICATIONS for accurate data

Wide frequency coverage to 25 mc, scanning width to 3 mc and sensitivity to 2μv plus many other exceptional performance characteristics enable the SPA-3/25 to provide accurate graphic measurement of virtually all types of signals; CW, AM, FM, pulsed, and noise. Its versatility and convenience for a multitude of applications have resulted in widespread acceptance.

The calibrated sweep width and center frequency controls are readily adjusted to select broadband scans or high resolution "zoomed in" analyses. Resolution capability is 200 cps. Crystal controlled markers check the frequency calibrations. The high persistence 5" CRT readout includes 3 selectable calibrated level scales; linear, 40 db log, and power. An adjustable smoothing filter facilitates single line noise density plotting. *(See screen photo at lower left)* Scanning rate is adjustable from 1 to 60 cps.

For applications requiring measurement only up to 15 mc, specify Model SPA-3. It includes all the outstanding features of the Model SPA-3/25. A companion Sweep Frequency Generator, Model G-6 is used with the SPA-3/25 or SPA-3 for single line response plotting to 15 mc. With the G-6, testing and alignment of filters, I-F's, and other networks are performed in a fraction of the time required for manual tuning methods.

Comprehensive technical bulletins are available on SPA-3/25, SPA-3, G-6, and other Panoramic instruments used from 0.5 cps to 44 kmc.

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International Conference on Precision Electromagnetic Measurements

NATIONAL BUREAU OF STANDARDS, BOULDER, COLO., AUGUST 14–17, 1962

The 1962 International Conference on Precision Electromagnetic Measurements, formerly Conference on Standards and Electronic Measurements, is co-sponsored by the National Bureau of Standards, Radio Standards Laboratory; IRE Professional Group on Instrumentation; and the American Institute of Electrical Engineers, Instrumentation Division.

As in 1958 and 1960 it is planned to publish all the conference papers in one issue of the IRE TRANSACTIONS on Instrumentation. Papers published will be those released by the different authors and approved by the editor, Prof. George B. Hoadley.

In accordance with other announcements the description, organization, and operation of standards laboratories will be given in a second conference, "Standards Laboratory Conference," Aug. 8–10, 1962.

Advanced programs and registration forms are available from: Mrs. Barbara Patterson, Boulder Labs., National Bureau of Standards, Boulder, Colo.

Facilities for the conference are limited and initial response indicates that the sponsors may be forced to limit registration. It will not be advisable to travel to Boulder without a confirmed reservation.

The sponsors wish to acknowledge a grant from the National Science Foundation in partial support of the conference.

The technical program is as follows:

Tuesday Morning, August 14

Introductory Remarks: *Dr. F. W. Brown, Director, Boulder Labs., National Bureau of Standards; Dr. J. M. Richardson, Chairman, 1962 ICPEM, Chief, Radio Standards Lab., National Bureau of Standards;* and *Dr. G. Birnbaum, Chairman, 1962 ICPEM Technical Program, Senior Scientist, Hughes Research Lab.*

Keynote Speaker: *Dr. R. D. Huntoon, Deputy Director, National Bureau of Standards.*

Session I—Space Electronics

Session Chairman: *S. Silver, University of California, Berkeley.*

"Measurement Problems of Space Vehicle Experiments," *W. E. Brown, Jr., Jet Propulsion Laboratory.*

"Error Sources in the Determination of the Astronomical Unit from Venus Radar Observations," *D. B. Holdridge, Jet Propulsion Laboratory.*

"A Direct Measurement of Charge Density in the F_2 Region," *D. D. McKibbin, Lockheed Missiles and Space Co.*

"Automatic Range Switching of Instrumentation in Space Vehicles for Increased Accuracy," *T. J. Crowther, Lockheed Missiles and Space Co.*

"Lunar Surface and Subsurface Magnetic Susceptibility Instrumentation," *E. M. Bollin, Jet Propulsion Lab.*

Tuesday Afternoon

Session II—Direct Current and Low Frequency Measurements

Session Chairman: *Chester Peterson, National Bureau of Standards.*

"Absolute Magnetic Susceptibilities by the Gouy and the Thorpe-Senftle Methods," *G. A. Candela and R. E. Mundy, National Bureau of Standards.*

"The Design and Performance of High-Precision Audio Frequency Current Transformers," *J. J. Hill, National Physical Lab., England.*

"A New Peak to DC Comparator for Audio Frequencies," *P. L. Richman, Rotek Instrument Corp.*

"Low-Power-Operated DC Instrument Transformers," *W. A. Geyger, U. S. Naval Ordnance Lab.*

"A Direct Reading Voltage Divider with Standard Cell Reference," *R. P. McKnight, Sandia Corp.*

Wednesday Morning, August 15

Session III—Data Reduction in Precision Measurements

Session Chairman: *W. J. Youden, National Bureau of Standards.*

"Uncertainties in Calibration," *W. J. Youden, National Bureau of Standards.*

"The Speed of Light," *A. G. McNish, National Bureau of Standards.*

"Automatic DC Data Logging System," *W. Arnett, Cohu Electronics Inc.*

Session IV—Properties of Materials

Session Chairman: *A. A. Oliner, Polytechnic Institute of Brooklyn.*

"DC Effects Accompanying Ferromagnetic Resonance in Thin Films," *H. J. Juretschke and L. M. Silber, Polytechnic Institute of Brooklyn.*

"Microwave Faraday Rotation Using a Bimodal Cavity," *D. P. Snowden, General Dynamics/General Atomic Div.*

"The Microwave Measurement of Narrow Line Width Ferromagnets by Radiated Fields," *A. D. Krall, U. S. Naval Ordnance Lab.*

"Measurement and Standardization of Dielectric Samples," *H. E. Bussey and J. E. Gray, National Bureau of Standards.*

Wednesday Afternoon

Session V—Quantum Electronics in Precision Measurements

Session Chairman: *R. C. Mockler, National Bureau of Standards.*

"Theoretical Considerations about the Measurement of Non-Linear Dielectric Constants," *N. Bloembergen, Harvard University.*

"The Use of Gaseous Optical Maser for Precision Measurements," *A. Javan, Massachusetts Institute of Technology.*

"Optically Pumped Rubidium Vapor as a Precision Magnetometer," *A. L. Bloom, Spectra Physics Inc.*

"Quantum Noise and Information Theory," *J. P. Gordon, Bell Telephone Labs., Inc.*

"The Proton Magnetic Resonance Oscillator, A Radio Frequency Source of High Spectral Purity," *A. Ganssen, National Company Inc.*

"The Measurement of Voltage by the Use of the Stark Effect," *Y. Beers and G. Strine, National Bureau of Standards.*

"A Proposed Measurement of the Velocity of Light Employing the Mössbauer Effect," *R. C. Mockler, National Bureau of Standards.*

Thursday Morning, August 16

Session VI—Atomic Frequency and Time (H_2, HCN, Other Molecules)

Session Chairman: *J. T. Henderson, National Research Council, Canada.*

"The Atomic Hydrogen Maser," *N. F. Ramsey and D. Kleppner, Harvard University.*

"Design and Performance of an Atomic Hydrogen Frequency Standard," *R. F. C. Vessot, Bomac Labs., Inc.*

"Hydrogen Cyanide Molecular Beam Type Maser," *D. Marcuse, Bell Telephone Labs., Inc.*

"Choice of Molecule for a Beam Frequency Standard," *F. S. Barnes, University of Colorado.*

Session VII—Atomic Frequency and Time (NH_3)

Session Chairman: *J. T. Henderson, National Research Council, Canada.*

"Ammonia Masers," *K. Shimoda, University of Tokyo.*

"$N^{15}H_3$ Double Beam Maser as a Primary Frequency Standard," *J. De Prins, University of Brussels.*

"Characteristics of the 3-2 Line Maser of $N^{14}H_3$ and the Precision of Frequency Comparison," *Y. Saburi, M. Kobayashi, and Y. Yasuda, Ministry of Posts and Telecommunications, Japan.*

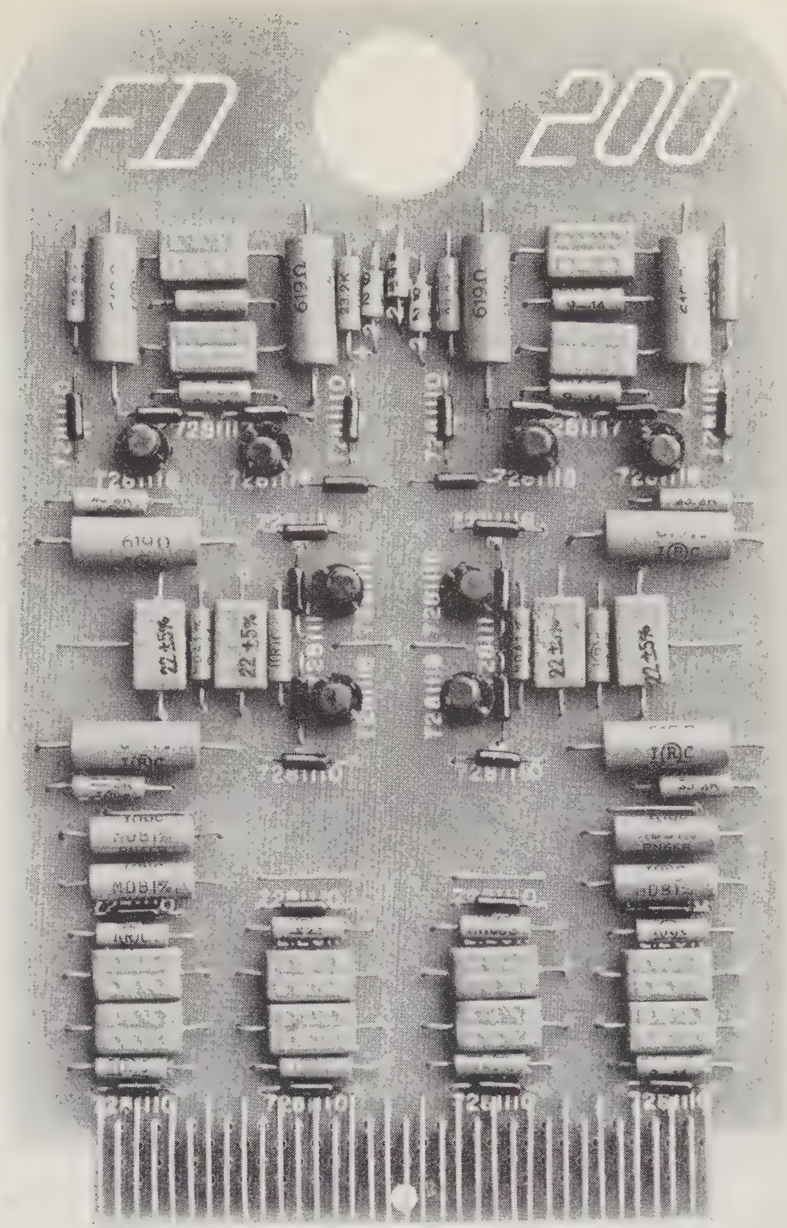
Thursday Afternoon

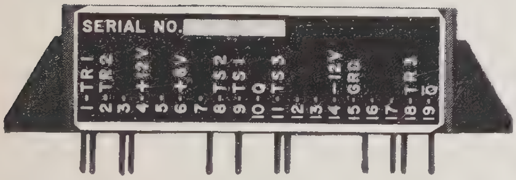
Session VIII—Atomic Frequency and Time (Rb, Cs, and Other Matters)

Session Chairman: *Louis Essen, National Physical Laboratory, England.*

"The Optically Pumped Rubidium Vapor Frequency Standard," *M. E. Packard, Varian Associates.*

"Operation and Improvements of a Cesium Beam Frequency Standard having 4 Meters Interaction Length," *P. Kartaschoff, Swiss Laboratory for Horological Research.*





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"A Comparison of Direct and Servo Methods for Utilizing Cesium Beam Resonators as Frequency Standards," *R. E. Beehler, W. R. Atkinson, L. E. Heim, and C. S. Snider, National Bureau of Standards.*

"The Atomic Time Scale," *W. Markowitz, U. S. Naval Observatory.*

"Performance of Precision Quartz Crystal Controlled Frequency Generators," *R. A. Sykes, W. L. Smith, and W. J. Spencer, Bell Telephone Labs., Inc.*

"Technique for Precise Measurement of Short or Long Term Stability of Oscillators," *H. F. Hastings and P. B. King, U. S. Naval Research Lab.*

Thursday Evening

Discussion: "An Atomic Definition for the Unit of Time," and "Determination of the Velocity of Light."

Friday Morning, August 17

Session IX—Microwave Power and Attenuation

Session Chairman: *Kiyo Tomiyasu, General Electric Co.*

"Microwave Power Measurements," *H. M. Barlow, University College, London.*

"Recent Works on Microwave Power-Measurements in Japan," *S. Okamura, University of Tokyo.*

"The Application of Hall Effect Devices to the Measurement of Microwave Power Density," *R. A. Leavenworth, J. Maczuk, and R. F. Schwartz, University of Pennsylvania.*

"A Millimeter-Wave Microcalorimeter," *K. Sakurai and T. Maruyama, Electrotechnical Lab., Tokyo.*

"Microwave Pulse Power Measurements," *C. A. Denney, C. L. Mavis, and J. Still, Sandia Corp.*

"Measurement of RF Peak Pulse Power by a Sampling-Comparison Method," *P. A. Hudson, W. L. Ecklund, and A. R. Ondrejka, National Bureau of Standards.*

"A High-Accuracy Microwave-Attenuation Standard for Use in Primary Calibration Laboratories," *A. V. James, Sperry Gyroscope Co.*

"A Precision Attenuation Standard for X-Band," *R. F. Clark and B. J. Dean, National Research Council, Canada.*

Friday Afternoon

Session X—Microwave Techniques

Session Chairman: *Harold M. Barlow, University College, London.*

"Swept Phase-Measurement Techniques with CW and Pulsed Signals," *S. B. Cohn, Rantec Corp.*

"A Phase Measuring System for Short RF Pulses," *R. A. Sparks, Emertron Inc.*

"A Technique for Precise Measurement of the Radio Frequency Structure of Pulsed Signals," *W. D. Griffin, HRB Singer Inc.*

"Report on the Standardization of High-Precision Coaxial Connectors," *F. J. Tischer, Ohio State University.*

"Improvements in Precision Coaxial Resistor Design," *D. Woods, Ministry of Aviation, England.*

"Microwave Measurements at 150 kMc." *J. B. Thaxter, Lincoln Lab.*

1962 Western Electronic Show and Convention

STATLER-HILTON HOTEL AND SPORTS ARENA, LOS ANGELES, CALIF., AUGUST 21–24, 1962

The 1962 Western Electronics Show and Convention will hold its technical sessions in the Statler-Hilton Hotel and its exposition in the Sports Arena, Los Angeles, Calif., Aug. 21–24, 1962. The theme will be "Frontiers in Electronics."

There will be twenty regular technical sessions, with five sessions presented concurrently each morning. Sessions will not directly be tied to "professional group" classifications—they will be made up according to the quality of papers available on any given subject.

WESCON's banquet will be held on Thursday evening, Aug. 23, in the Biltmore Bowl of the Biltmore Hotel. Dr. A. Zarem, President of Electro-Optical Systems, Pasadena, will be toastmaster. Principal speaker will be E. W. Engstrom, President of the Radio Corporation of America.

Individual preprints of WESCON Technical papers will be available during the show. Special sessions and invited sessions, however, may be presented without formal papers.

The program is as follows:

Tuesday Morning, August 21

Session I—Circuit Theory

Chairman: *R. C. Booton, Space Technology Lab., Redondo Beach, Calif.*

"Distributed Parameter Circuit Design Techniques," *P. S. Castro, A. J. Nichols, and H. R. Kaiser, Lockheed Missiles and Space Company, Palo Alto, Calif.*

"Transfer Function Synthesis Employing One Tunnel Diode and a Passive RC Ladder Network," *G. Herskowitz and M. S. Ghausi, New York University, New York, N. Y.*

"Minimum Period of Oscillation of Tunnel-Diode Oscillators," *R. S. Pepper, University of California, Berkeley, Calif.*

"High Power Parametric Upper Sideband Upconverters," *H. Y. Miyahira, Space Technology Lab., Inc., Redondo Beach, Calif.*

Session II—Computer Memories

"A Practical Nondestructive Random Access Tunnel Diode Memory," *J. Y. Payton, Litton Systems, Inc., Woodland Hills, Calif.*

"The Design of a 4096 Word One Microsecond Magnetic Film Store," *J. B. James, B. J. Steptoe, and A. S. Kaposi, Internat'l. Computers and Tabulators Ltd., Stevenage, Hertfordshire, Eng.*

"Inductive Coupled Read-Only Memory," *J. G. Wamsley, IBM Corp., Poughkeepsie, N. Y.*

Session III—Instrumentation

Chairman: *E. N. Kaufman, Litton Systems, Inc., Woodland Hills, Calif.*

"Spectrum Analysis Techniques," *A. Basil, Cutler Hammer, Melville, L. I., N. Y.*

"A Hall Effect Incremental Angle Encoder," *E. R. Strandt, General Motors Corp., Milwaukee, Wis.*

"Properties and Applications of a Sensitive Magnetic Transducer," *A. P. Schmid and W. Rindner, Raytheon Co., Waltham, Mass.*

"Coding for Least Rms Error in Binary PCM Channels," *J. Bodo, Ampex Corp., Redwood City, Calif.*

"A New p-n Junction Strain Transducer," *W. Rindner and R. Nelson, Raytheon Co., Waltham, Mass.,*

Session IV—Space Electronics and Telemetry

Chairman: *W. S. Pope, North American Aviation, Downey, Calif.*

"Ionosphere Plasma Frequency Probe," *O. C. Haycock and K. D. Baker, University of Utah, Salt Lake City, Utah.*

"An Integrated Satellite Tracking and Communication System," *L. Farkas, Radio Corporation of America, Moorestown, N. J.*

"Antenna Beam Elevation Angle for Control of Tropospheric Interference Between Space/Earth and Terrestrial Stations," *S. G. Lutz, Hughes Research Lab., Malibu, Calif.; and W. J. Hartmen, U. S. Bureau of Standards, Boulder, Colo.*

"Considerations on Communication with Intelligent Life in Outer Space," *M. Handelsman, Radio Corporation of America, Princeton, N. J.*

Session V—Component Parts

Chairman: *J. E. Fort, National Cash Register Co., Hawthorne, Calif.*

"Optimized Design of Transformers for Application in Silicon Controlled Rectifier Extinction and Ignition Circuits," *R. J. Hruby, Nortronics, Anaheim, Calif.*

"Power Transistor Reliability," *A. Ralph Greenburg, Motorola Inc., Phoenix, Ariz.*

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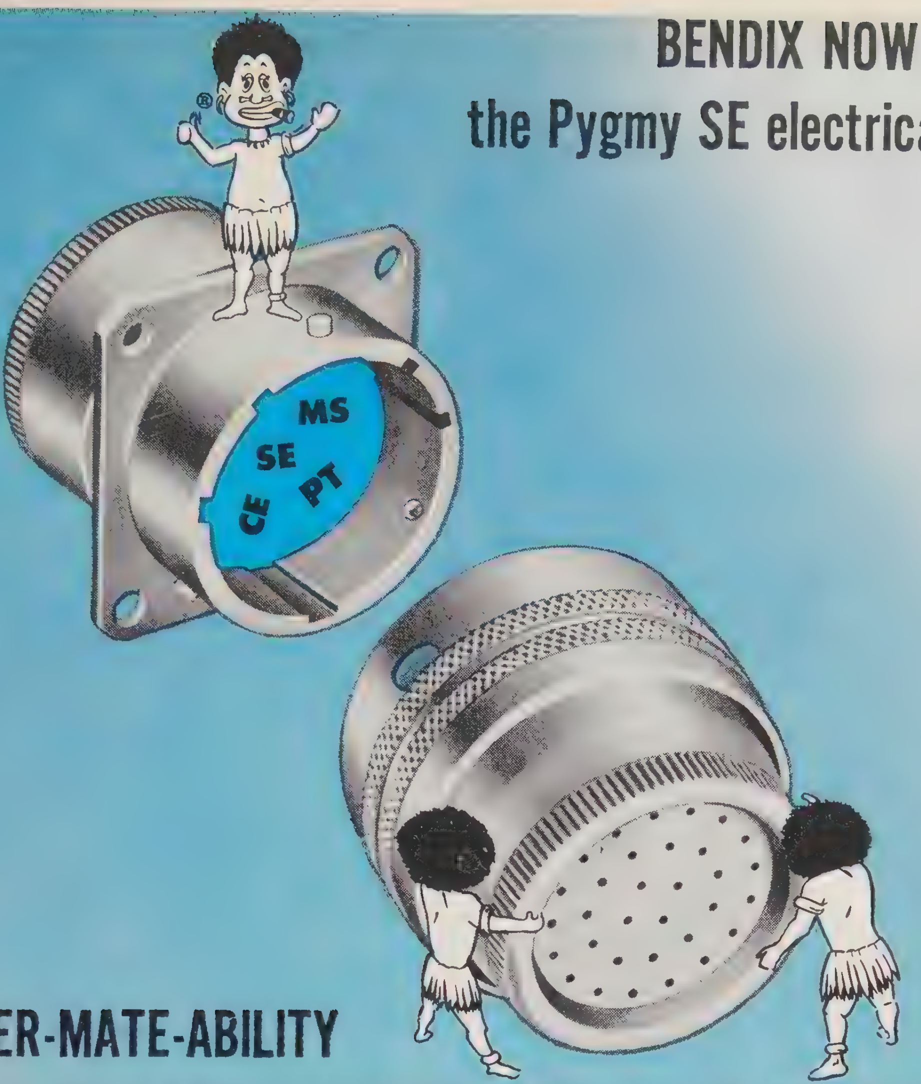

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"Optimum Design of Medium Power Transistor Heat Sinks," *Dr. H. Tramposch, IBM Corp., Poughkeepsie, N. Y.*

"Cause and Correction of Phase Distortion in Pulse Excited Long Ultrasonic Delay Lines," *P. S. Fuss and R. M. Lauver, Bell Telephone Co., Whippany, N. J.*

Tuesday Afternoon

Session A—Special Invited Session

"Biological Aspects of Communications," *Prof. W. A. Rosenblith, Massachusetts Institute of Technology.*

"Biological Information Transfer on the Molecular Level," *Prof. A. Rich, Massachusetts Institute of Technology.*

Wednesday Morning, August 22

Session VI—Pattern Recognition

"An Optical Decision," *R. D. Joseph, P. M. Kelly, and S. S. Viglione, Astropower, Inc., Costa Mesa, Calif.*

"A Recognition Logic Designed for Hand Printed Characters," *S. Spilerman, IBM Corp., New York, N. Y.*

"The Application of Integral Geometry to Machine Recognition of Visual Patterns," *G. H. Ball, ITT Federal Labs., Palo Alto, Calif.*

"A Machine for Performing Visual Recognition, by Use of Antenna-Propagation Concepts," *H. Blum, Cambridge Research Lab., U. S. Air Force, Bedford, Mass.*

Session VII—Microwave Theory and Techniques

Chairman: *A. Clavin.* "Microwave Phase Measurement of Dispersed Pulse Transmitter Systems," *R. F. Koontz, Radio Corporation of America, Moorestown, N. J.*

"4 Gc Parametric Amplifier for Satellite Communication Ground Station Receiver," *M. Uenohara, M. Chruney, K. M. Eisele, D. C. Hanson, and A. L. Stillwell, Bell Telephone Lab., Murray Hill, N. J.*

"Advances in Ferrite Rotating-Field Phaser Design," *J. A. Weiss, Hyletronics Corp., Burlington, Mass.*

"Practical Problems in the Design of Tunnel Diode Amplifiers," *J. C. Hoover, Sperry Microwave Electronics Co., Clearwater, Fla.*

Session VIII—Computer Mechanization

"Theoretical and Experimental Evaluation of RZ and NRZ Recording Characteristics," *I. Stein and M. F. Barkouki, Ampex Corp., Redwood City, Calif.*

"A Unified Approach to the Design of Solid-State Integrated Logic Elements," *R. H. Beeson and O. R. Baker, Signetics Corp., Sunnyvale, Calif.*

"Experimental 100-mc Tunnel-Diode DDA," *E. R. Beck and G. A. Brumm,. The Bendix Corp., Southfield, Mich.*

Session IX—Aeronautical and Navigational Electronics

Chairman: *S. Z. Szirmay, Jet Propulsion Lab., Pasadena, Calif.*

"An Accuracy Study of A Doppler Navigation System Assuming Time-Stationary Random Input Errors," *C. James Styers, Collins Radio Co., Cedar Rapids, Iowa.*

"Mark Twain Beaconry for Lunar Orbiting and Landing," *W. E. Muntz, General Electric Co., Utica, N. Y.*

"High Altitude Radio Altimeter Simulation Study," *A. R. Edison, R. K. Moore, B. D. Warner, and W. W. Koepsel, University of New Mexico, Albuquerque, N. Mex.*

"Two Methods of Gyroless Navigation," *E. Ohlberg, Nortronics, Palos Verdes Estates, Calif.*

Session X—Product Engineering and Production

Chairman: *G. R. Beck, Space Technology Lab., Redondo Beach, Calif.*

"A New Approach to Miniature Tape Transport Design," *R. S. Anderson, Weber Aircraft Corp., Burbank, Calif.*

"Weldable Printed Circuits," *D. Grabbe, G. Messner, and J. Saffery, Photocircuits Corp., Glen Cove, N. Y.*

"A Logically Consistent System of Components and Techniques for Transistorized Radio Sets," *I. J. Rodrigues de Miranda, Philips, Eindhoven-Nederland.*

Wednesday Afternoon

Session B—Special Invited Session

"Weather Satellites and Data Processing," *D. Johnson, Deputy Director, Meteorlogical Satellite Activities, U. S. Weather Bureau, Washington, D. C.*

Session C—Special Invited Session

"Research in Nuclear Test Detection," *Dr. G. F. Bing, Assistant Director for Nuclear Test Detection, Advanced Research Projects Agency, Washington, D. C.*

Thursday Morning, August 23

Session XI—Computer Theory

"The Standardization of Peripheral Interfaces," *M. Jacoby, Remington Rand Univac, Blue Bell, Pa.*

"A Real Time Function Analyzer-Synthesizer Using Orthogonal Polynomials," *A. H. Ballard, Bernard Electronics Co., Washington, D. C.*

"In Expensive Control via Modal Computers," *F. G. Steele, Modal Systems, Inc., La Jolla, Calif.*

Session XII—Antennas and Propagation

Chairman: *K. C. Kelly, Hughes Aircraft Co., Culver City, Calif.*

"Range Lunar Capsule Antenna," *W. G. Scott, Ford Motor Co., Newport Beach, Calif.*

"A Self-Focusing Antenna," *M. Breese and P. Sferrazza, Sperry Gyroscope Co., Great Neck, N. Y.*

"The 'Double Helix' and its Variants: A New Class of Tunable Endfire Antennas," *H. W. Ehrenspeck, Cambridge Research Lab., U. S. Air Force, Bedford, Mass.*

"Antenna Beam Shifting by Dual Modes," *T. Kitsuregawa and S. Tachikawa, Mitsuhishi Electric Mfg. Co., Amagasaki Hyogo Prefecture, Japan.*

Session XIII—Solid-State Devices

Chairman: *J. Black, El Monte, Calif.*

"Instrumental Neutron Activation Analysis of Silicon Semi-Conductors for Gold and Antimony," *J. D. Buchanan, D. M. Fleishman, V. P. Buinn, and R. R. Ruch, General Dynamics Corp., San Diego, Calif.*

"Surface Stabilized High Voltage Diodes," *T. C. Hall, Micro Semiconductor Corp., Culver City, Calif.*

"Planar Epitaxial PNPN Switch with Gate Turn-Off Gain," *T. A. Longo, M. Miller, A. E. Derek, and J. D. Eknaian, Sylvania Electric Products, Inc., Woburn, Mass.*

"Linotron—A Practical Device for Majority Logic," *W. D. Rowe, Sylvania Electronic Systems, Needham, Mass.; and C. D. Simmons, Philco Corp., Lansdale, Pa.*

Session XIV—Communication Systems

Chairman: *L. R. Norwood, Aerospace Corp., El Segundo, Calif.*

"The Design and Capabilities of Feedback FM Receivers," *R. M. Gagliarde, Hughes Aircraft Co., Culver City, Calif.*

"Chirp Signals for Communications," *M. R. Winkler, Radio Corporation of America, Tucson, Ariz.*

"Real Channel Aspects of an Error-Free Data Transmission System for Toll-Grade Telephone Circuits," *W. G. Schmidt, Massachusetts Institute of Technology, Lexington, Mass.*

"The Application of Correlation Techniques to Meteor Burst Communications," *J. D. Belenski, The Boeing Co., Seattle, Washington.*

Session XV—Reliability and Quality Control

"Failure Therblig Failure Rates," *D. R. Earles and M. F. Eddins, AVCO Corp., Wilmington, Mass.*

"Optimizing Reliability," *J. C. Kemp, General Electric Co., Ithaca, N. Y.*

"High Power Life Testing of Transistors," *K. W. Doversberger, Delco Radio Div., General Motors Corp., Kokomo, Ind.*

"The Reliability of Systems Under Random Demands," *K. M. Hall and K. M. Zenkere, Sylvania Electronic Products, Inc., Mountain View, Calif.*

Thursday Afternoon

Session D—Special Invited Session

"Advanced Power Propulsion Systems," *moderator: Dr. A. M. Zarem, Electro Optical Systems, Inc.*

Friday Morning, August 24

Session XVI—General Topics in Information Theory

"Adaptive Information Processing," *S. S. L. Chang, New York University, New York, N. Y.*

"Maximal Paths on the N-Cube and Generation of Codes," *I. T. Frisch and W. H. Kim, Columbia University, New York, N. Y.*

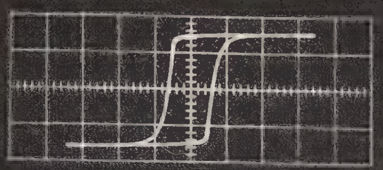
"A Comparative Evaluation of Sequential Decoding Algorithms," *D. M. Johes, W. R. Wadden, and J. J. Bussgang, Radio Corporation of America, Burlington, Mass.*

"A Reconsideration of Certain Topics in Nyquist's Telegraph Transmission Theory," *R. A. Gibby, Bell Telephone Lab., Murray Hill, N. J.*

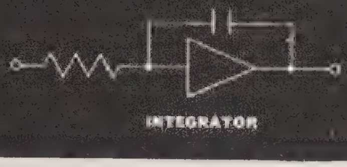
Session XVII—Electron Devices II

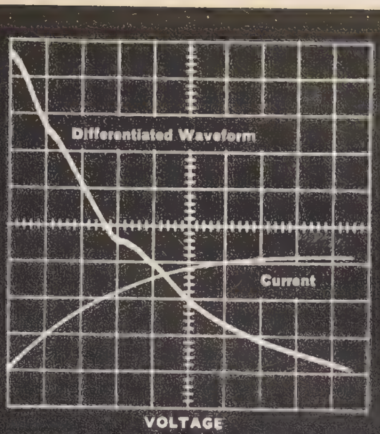
"Recent Developments in Field Emission," *W. P. Dyke, F. M. Charbonnier and F. J. Grundhauser, Field Emission Corp., McMinnville, Ore.*

"Design Method for High Convergence High Perveance Solid Beam Guns," *R. D.*

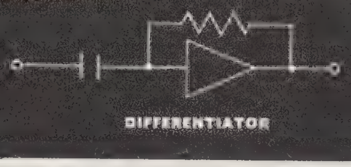


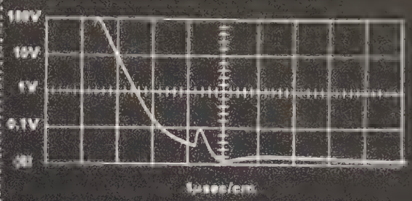
DISPLAY OF INTEGRATED WAVEFORM—transformer secondary voltage integrated and plotted against the transformer primary current—for enabling study of B-H loops of transformer cores.





DISPLAY OF DIFFERENTIATED WAVEFORM—tunnel diode in liquid helium—for enabling detection of quantum phenomena at low temperature.





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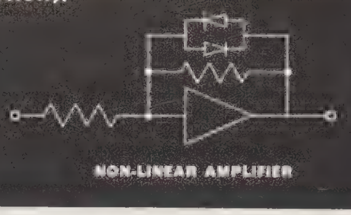
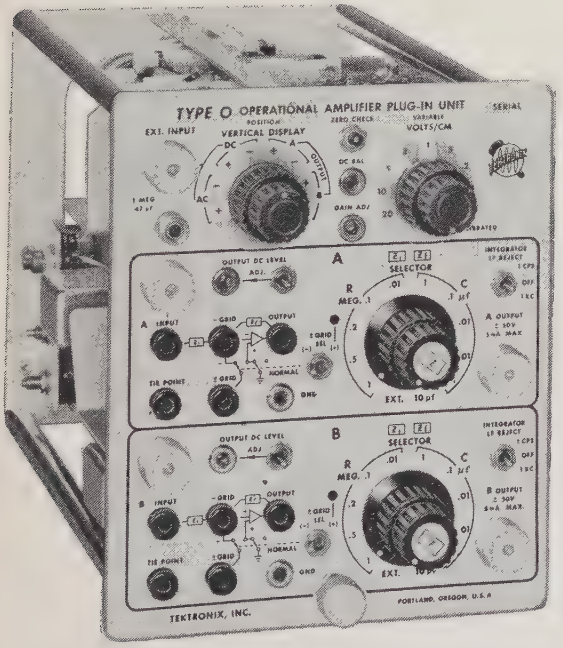


New Operational Amplifier Plug-In Unit Permits Oscilloscope Measurements Under Dynamic Conditions



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Frost, O. T. Purl, and H. R. Johnson, Watkins-Johnson Co., Palo Alto, Calif.

"AD-C Pumped Coupled Mode Parametric Amplifier With Depressed Collector," *J. E. Dalley and C. C. Johnson, University of Utah, Salt Lake City, Utah.*

"Recent Advances in Non-Reentrant-Crossed-Field, Forward-Wave Amplifiers," *J. F. Hill, G. E. Pokorny, and C. P. Kooyers, Litton Industries, San Carlos, Calif.*

Session XVIII—Automatic Control

Chairman: *W. K. Waymeyer, Douglas Aircraft Co., Santa Monica, Calif.*

"State Transition Flow Graphs of Continuous and Sampled Dynamic Systems," *B. C. Kuo, University of Illinois, Urbana, Ill.*

"Stability of Sampled-Data Control Systems, A Simple Criterion," *P. W. Becker, General Electric Co., Syracuse, N. Y.*

"Highfrequency Signal Injection: A Means of Changing the Transfer Characteristics of Nonlinear Elements," *O. I. Elgerd, University of Florida, Gainesville, Fla.*

"On the Optimum Design of Predictor Control Systems," *Sheldon Horing, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.*

Session XIX—Military Electronics

Chairman: *P. F. Glaser, Space Technology Lab., Redondo Beach, Calif.*

"Optimal Bang-Bang Guidance System," *G. L. Harman, K. E. Kent, and W. O. Purcell, Martin Marietta Corp., Orlando, Fla.*

"Performance of Digital Communication Systems in an Arbitrary Fading Rate and Jamming Environments," *A. B. Glenn and G. Lieberman, Radio Corporation of America, Camden, N. J.*

"Electromagnetic Susceptibility Testing Techniques for Airborne Equipment," *C. B. Pearlston, Jr., Nortronics, Hawthorne, Calif.*

"Long-Range CW Radar," *B. E. Potter, Sperry Gyroscope Co., Great Neck, L. I., N. Y.*

Session XX—Engineering Management

Chairman: *C. McPheeters, Pacific Missile Range, Point Mugu, Calif.*

"Communications for the Engineering Manager," *J. B. Bennett, Organizational Communication, Los Angeles, Calif.*

"Some Aspects of the Policy for the Formulation of Naval Activity Long Range Plans (LRP)," *L. E. Wood, U. S. Naval Missile Center, Point Mugu, Calif.*

"A Simplified Work-Load Evaluation and Cost Control Method for Report Production," *P. Alelyunas, Radio Corporation of America, Moorestown, N. J.*

Friday Afternoon

Session E—Lunar Exploration (Special Invited Session)

Chairman: *R. J. Gunkel, Douglas Aircraft Co., Missile and Space Systems Div., Santa Monica, Calif.*

"Progress Report on Ranger," *J. B. Burke, Ranger Project Manager, JPL; and M. R. Mesnard, JPL.*

"Progress Report on Surveyor," *W. E. Giberson, Surveyor Project Manager, JPL.*

"Progress Report on Saturn," *Dr. O. H. Lange, George C. Marshall Space Flight Center, NASA, Huntsville.*

"Progress Report on Apollo," *C. W. Frick, Manned Spacecraft Center, NASA, Houston, Tex.*

1962 International Symposium on Information Theory

UNIVERSITÉ LIBRE DE BRUXELLES, BRUSSELS, BELGIUM, SEPTEMBER 3–7, 1962

The Symposium is sponsored by the IRE Professional Group on Information Theory and organized jointly by the Benelux Section of the IRE and the Société Belge des Ingénieurs des Telecommunications et d'Electronique with the cooperation of the Université Libre de Bruxelles.

The papers to be given at the Symposium will be published in August as a special issue of the IRE TRANSACTIONS on Information Theory, which may be ordered from IRE Headquarters ($5. for IRE members, $10. for nonmembers.)

Information about registration may be obtained from: P. Selleslags, Lab. d'Electricité Générale, Université Libre de Bruxelles, 50 Avénue F. D. Roosevelt, Bruxelles 5, Belgique.

The technical program is as follows:

Monday Morning, September 3

Welcome: *Prof. J. A. J. L. Hoffmann, Vice Chairman, Organizing Committee.*

Introductory remarks: *Dr. F. L. Stumpers, Chairman, Organizing Committee.*

Session I—Coding (I)

"On a Class of Efficient Error-Limiting Variable-Length Codes," *P. G. Neumann, Bell Telephone Labs., Murray Hill, N. J., U.S.A.*

"A Weight Formula for Group Codes," *G. Solomon, Jet Propulsion Lab., Pasadena, Calif., U.S.A.*

"The Use of Information Sets in Decoding Cyclic Codes," *E. Prange, Air Force Cambridge Research Labs., Bedford, Mass., U.S.A.*

"The Generation of Impulse-Equivalent Pulse Trains," *D. A. Huffman, Dept. of Elec. Engineering, Massachusetts Inst. of Tech., Cambridge, Mass., U.S.A.*

Monday Afternoon

Session II—General Theory (I)

"Signal Detection Under Noise Interference in a Game Situation," *Lars-Henning Zetterberg, Swedish Airplane Co., Stockholm, Sweden.*

"The Effect of Statistically Dependent Interference on Channel Capacity," *N. M. Blachman, Electronic Defense Labs., Sylvania Electronic Systems, Mountain View, Calif., U.S.A.*

"Optimum Multiple-Input Nonlinear System with Gaussian Inputs," *D. A. Chestler, Applied Research Lab., Sylvania Electronic Systems, Waltham, Mass., U.S.A.*

"Bayes Optimum Filters Derived Using Wiener Canonical Forms," *D. B. Brick and G. Zames, Applied Research Lab., Sylvania Electronic Systems, Waltham, Mass.*

"A New Sampling Principle for the Determination of Averages of a Stationary Random Time Function, and its Application to a Digital Correlator," *P. Jespers, Univ. Catholique de Louvain, Louvain, Belgium; and H. Chu, Bell Telephone Co., Antwerp, Belgium.*

Tuesday Morning, September 4

Session III—Pattern Recognition

"Learning to Recognize Patterns in a Random Environment," *N. Abramson, Elec. Engrg. Dept., Stanford University, Stanford, Calif., U.S.A.; and D. J. Braverman, California Inst. of Tech., Pasadena, Calif., U.S.A.*

"On the Use of Boolean Functions in Pattern Recognition," *S. R. Petrick, Air Force Cambridge Research Labs., Bedford, Mass., U.S.A.*

"On Designs for Automatic Recognition of Patterns in Noise," *A. E. Basharinov, Institute of Radio Engineering and Electronic Physics, Moscow, U.S.S.R.*

"An Approach to General Pattern Recognition," *M. Fischler, R. L. Mattson, O. Firschein, and L. D. Healy, Lockheed Missiles and Space Co., Sunnyvale, Calif., U.S.A.*

"A Consistency Technique for Pattern Association," *J. R. Ullmann, National Physical Lab., Teddington, Middlesex, U.K.*

Tuesday Afternoon

Session IV—Speech and Music

"Pattern Recognition by an Adaptive Process of Sample Set Construction," *G. S. Sebestyen, Litton Systems, Waltham, Mass., U.S.A.*

"The Information Rate of the Pitch Signal in Speech," *T. Koshikawa and T. Sugimoto, Electronical Comm. Lab., Tokyo, Japan.*

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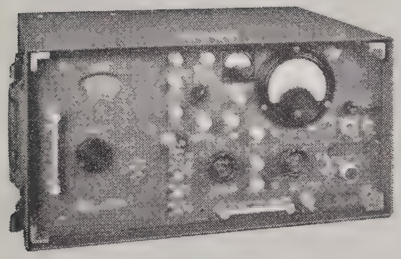

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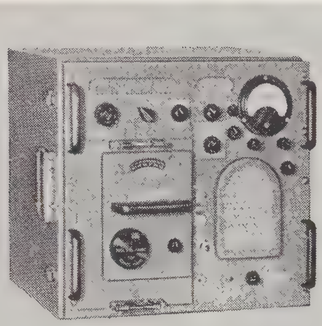

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"Voice Excited Vocoders for Practical Speech Bandwidth Reduction," *E. E. David, M. R. Schröder, B. F. Logan, and A. J. Prestigiacomo, Bell Telephone Labs., Murray Hill, N. J., U.S.A.*

"Mathematical Analysis of Formal Structure in Music," *W. Fucks, Physikalisches Institut der Technischen Hochschule, Aachen, Germany.*

Wednesday Morning, September 5

Session V—Applications to Communication Systems (I)

"Détermination Approximative de la Position Extrème du Seuil Reception en Modulation de Fréquence," *G. Battail, Centre National d'Etudes des Télécommunications, Paris, France.*

"The Threshold Effect in Modulation Systems that Expand Bandwidth," *D. Slepian, Bell Telephone Labs., Murray Hill, N. J., U.S.A.*

"Seco: A Self-Regulating Error Correcting Coder-Decoder," *K. E. Perry and J. M. Wozencraft, Lincoln Lab., Mass. Inst. of Tech., Lexington, Mass., U.S.A.*

"Co-Modulation: A New Method for High-Speed Data Transmission," *F. de Jager and P. J. van Gerwen, Philips Research Labs., Eindhoven, Netherlands.*

"Sur la Limitation Spectrale et la Fréquence Instantanée des Signaux," *J. Oswald, Comp. Industrielle des Téléphones, Paris, France.*

Wednesday Afternoon

Session VI—Human Information Processing

"Mathematical Models for the All-Or-None Activity of some Neurons," *G. L. Gerstein, Research Lab. of Electronics, Mass. Inst. of Tech., Cambridge, Mass., U.S.A.*

"A Theory of Cortical Organisations and Learning," *W. K. Taylor, Dept. of Elec. Engrg., University College, London, U.K.*

"Quelques Résultats Théoriques et empiriques Concernant l'Accomodation Informationelle," *H. Frank, Inst. Nachrichtenverarbeitung der Technischen Hochschule, Karlsruhe, Germany.*

"Sequential Phenomena in Psychophysical Judgments: A Theoretical Analysis," *R. C. Atkinson, Stanford Univ., Stanford, Calif.; E. C. Carterette, Univ. of California; and R. A. Kinchla, Ames Research Center, Calif., U.S.A.*

"Human Search Characteristics in the Space and Time Domains," *N. S. Potter, Radio Corporation of America, Defense Electronic Products, Moorestown, N. J., U.S.A.*

Thursday Morning, September 6

Session VII—Adaptive Systems (I)

"An Experimental Comparison of Some Algorithms for Self-Organizing Systems," *A. M. Andrew, National Physical Lab., Teddington, Middlesex, U.K.*

"Adaptive Communication Filtering," *C. S. Weaver, Philco Western Development Labs., Palo Alto, Calif., U.S.A.*

"Design Principles for an Intelligent Machine," *M. E. Maron, The RAND Corp., Santa Monica, Calif., U.S.A.*

"Matrix Structure in the Simulation of Learning," *S. N. Braines and V. B. Svechinsky, Biocybernetical Inst., Univ. of Moscow, Moscow, U.S.S.R.*

"The Logic and Behaviour of Self-Organizing Systems as Illustrated by the Interaction Between Man and Adaptive Machines," *G. Pask, Systems Research Ltd., Richmond, Surrey, U.K.*

Thursday Afternoon

Session VIII—General Theory (II)

"On Instantaneous Entropy," *W. H. Foy, Martin Co., Baltimore, Md., U. S.A.*

"Information Capacity of a Time-Continuous Channel," *R. J. Huang and R. A. Johnson, Dept. of Elec. Engr., Syracuse University, Syracuse, N. Y., U.S.A.*

"Coding and Decoding for Time-Discrete Amplitude-Continuous Memoryless Channels," *J. Ziv, Scientific Dept., Ministry of Defence, Tel-Aviv, Israel.*

"System Performance in the Presence of Stochastic Delays," *W. M. Brown and C. J. Palermo, Inst. of Science and Technology, Univ. of Michigan, Ann Arbor, Mich., U.S.A.*

"Optimum Message Transmission in a Finite Time," *S. S. L. Chang, B. Harris, and J. J. Metzner, College of Engrg., New York Univ., New York, N. Y., U.S.A.*

"Basic Theorems of the Constructive Information Theory," *B. S. Fleishman, Inst. of Radio Engineering and Electronic Physics, Moscow, U.S.S.R.*

Friday Morning, September 8

Session IX—Adaptive Systems (II)

"Learning Process and Inverse-H Theorem," *S. Watanabe, IBM Watson Research Lab., Yorktown Heights, N. Y., U.S.A.*

"Mechanisms of the Selection of Useful and Trustful Information," *V. Napalkov, Dept. of Physiology of Higher Nervous Activity, Univ. of Moscow, Moscow, U.S.S.R.*

"Synchronization Methods for Block Codes," *J. J. Stiffler, Jet Propulsion Lab., Pasadena, Calif., U.S.A.*

"An Electronic Decoder for Bose-Chaudhuri-Hocquenghem Error-Correcting Codes," *T. C. Bartee and D. I. Schneider, Lincoln Lab., Mass Inst. of Tech., Lexington, Mass., U.S.A.*

Friday Afternoon

Session X—Applications to Communication Systems (II)

"A Solution to the Problem of Compatible Single-Sideband Transmission," *B. F. Logan and M. R. Schroeder, Bell Telephone Labs., Murray Hill, N. J., U.S.A.*

"Measurements on Time-Variant Communication Channels," *T. Kailath, Jet Propulsion Lab., Pasadena, Calif., U.S.A.*

"Error Probabilities for Adaptive Multichannel Reception of Binary Signals," *R. Price, Lincoln Lab., Mass. Inst. of Tech., Lexington, Mass., U.S.A.*

"Some Properties of the Finite Convolution," *J. A. Sheehan, the MITRE Corp. Bedford, Mass., U.S.A.*

"Information Transmission with Additional Noise," *R. L. Dobrushin and B. S. Tsybakov, Institute of Radio Engineering and Electronic Physics, Moscow, U.S.S.R.*

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Antennas and Propagation (G-3)—Dr. H. Fine, Applied Propagation Branch, Technical Research Div., FCC, Washington, D. C.; S. A. Bowhill, Pennsylvania State Univ., University Park, Pa.

Audio (G-1)—R. W. Benson, Elec. Engrg. Dept., Vanderbilt University, Nashville 5, Tenn.; M. Camras, Armour Res. Foundation, Tech. Ctr., Chicago 16, Ill.

Automatic Control (G-23)—L. B. Wadel, 3546 Caruth Blvd., Dallas 25, Tex.; G. S. Axelby, Westinghouse Air Arm Div., Friendship Airport, Baltimore 3, Md.

Bio-Medical Electronics (G-18)—G. N. Webb, Dept. of Medicine, Biophysical Div., Johns Hopkins Hospital, Baltimore 5, Md.; L. B. Lusted, Dept. of Radiology, Univ. of Rochester, Rochester 20, N. Y.

Broadcast and Television Receivers (G-8)—J. F. Bell, Zenith Radio Corp., 6001 W. Dickins Ave., Chicago 39, Ill.; C. W. Sall, RCA, Princeton, N. J.

Broadcasting (G-2)—R. F. Guy, 264 Franklin St., Haworth, N. J.; W. L. Hughes, School of Elec. Engrg., Oklahoma State University, Stillwater, Okla.

Circuit Theory (G-4).—Dr. J. H. Mulligan, Jr., College of Engrg., New York Univ., University Heights, New York 53, N. Y.; M. E. Van Valkenburg, Dept. of E.E. Univ. of Illinois, Urbana, Ill.

Communications Systems (G-19)—R. L. Marks, Rome Air Dev. Ctr., Griffiss AFB, N. Y.; E. J. Baghdady, Elec. Engrg. Dept., M.I.T., Cambridge 39, Mass.

Components Parts (G-21)—L. Kahn, Astron

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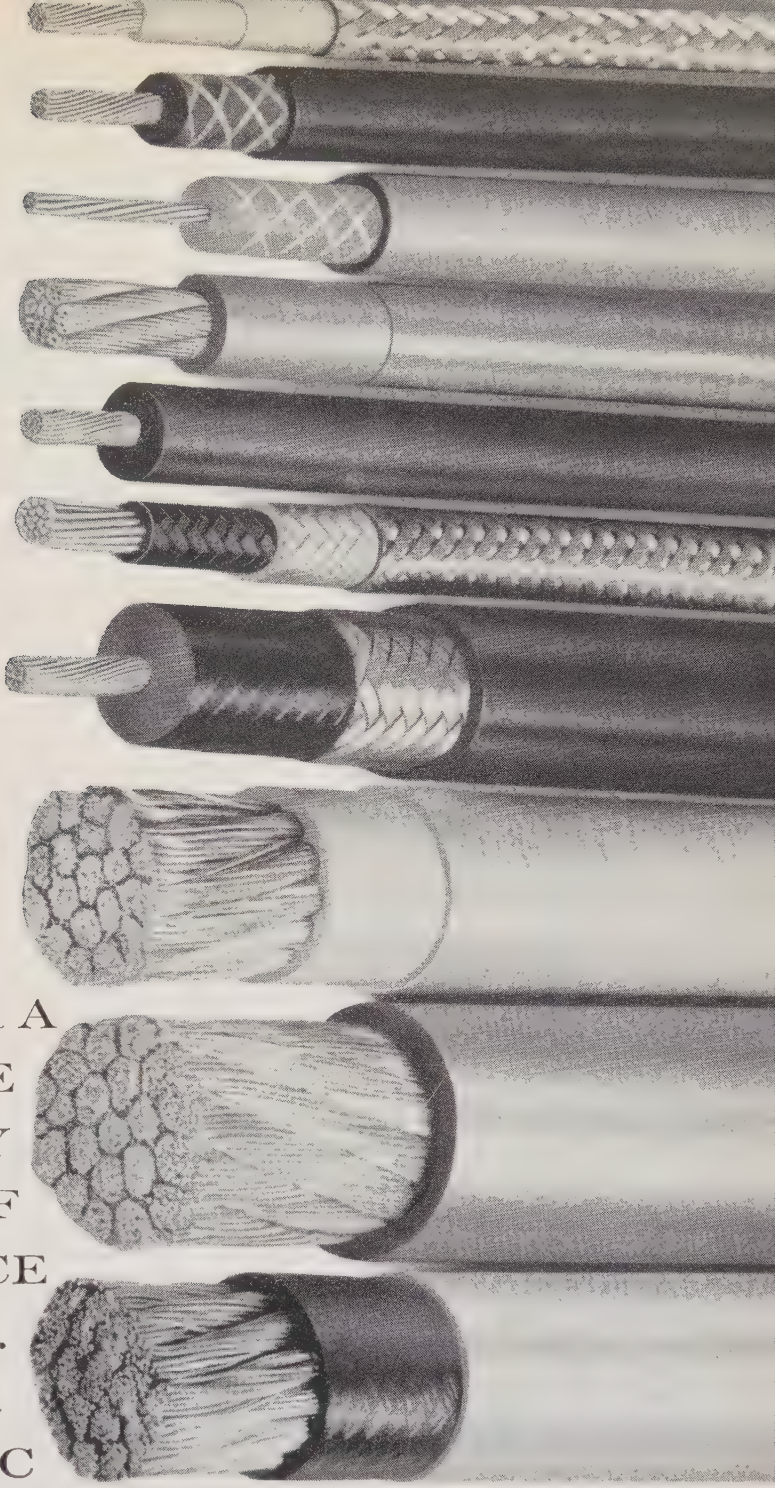

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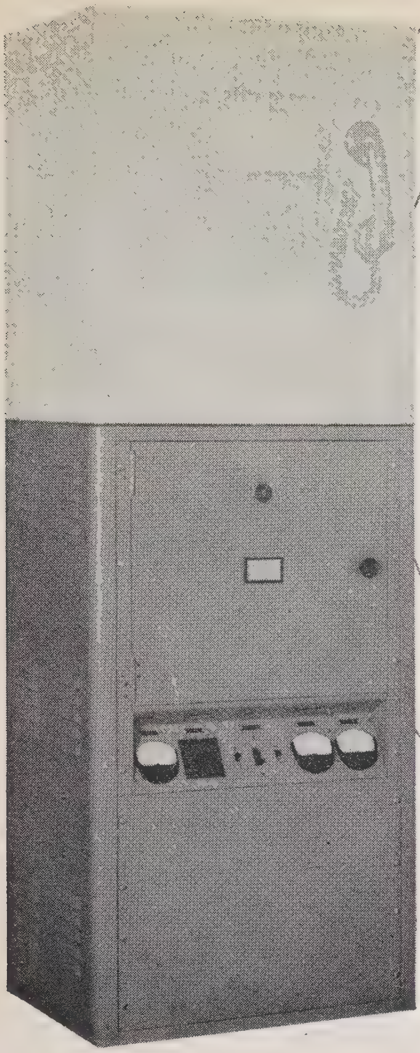

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- **#52 Frequency and Time Standards**
- **#53 Transmission Line Testing Using the Sampling Oscilloscope**
- **#54 Improvements in Microwave Swept Frequency Techniques**
- **#56 Microwave Mismatch Error Analysis**
- **#57 Noise Figure Primer**

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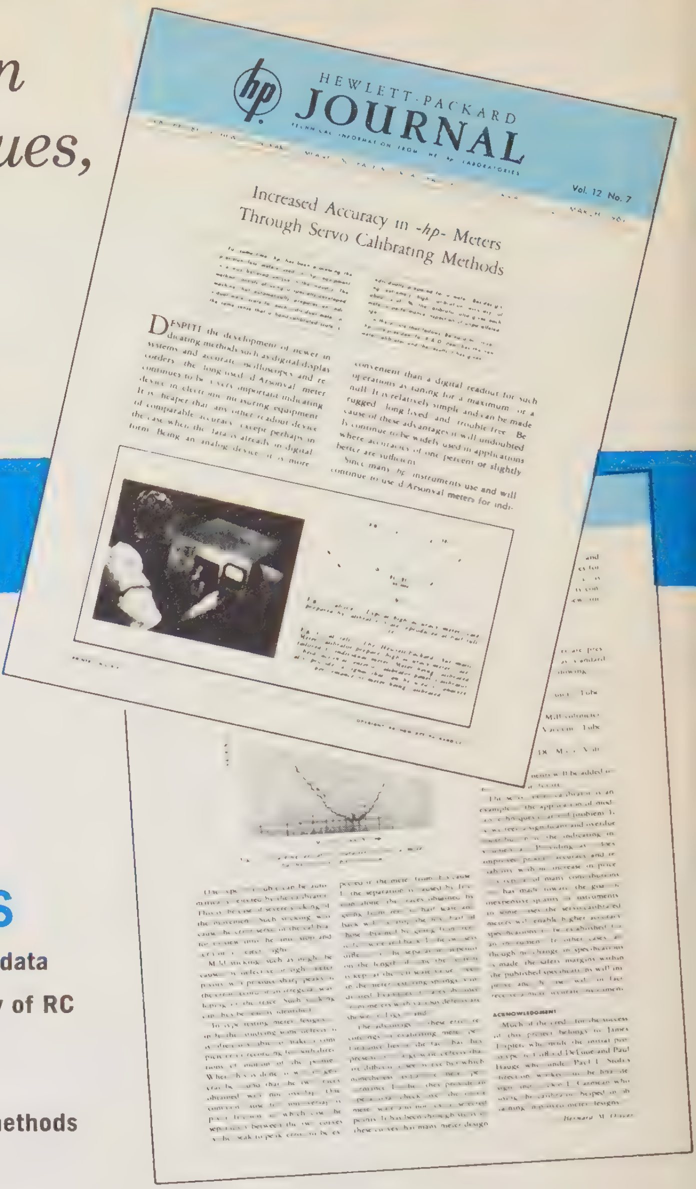
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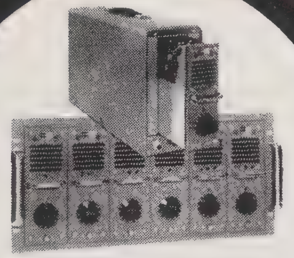

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Industrial Engineering Notes*

ASSOCIATION ACTIVITIES

EIA Director Robert C. Sprague expects the value of the components industry's output to reach $6.9 billion a decade from now, he said in a keynote address before the Electronic Components Conference in Washington last week. The total will include $1 billion worth of microcircuits of all types, including planar and molectronic, and passive discrete parts valued at more than $3 billion, he said. By 1967 production value is expected to reach $5.4 billion, of which some $400 to $500 million will be in all types of microcircuits, including planar and molectronic. Mr. Sprague, Board Chairman and Treasurer of Sprague Electric, compared the production predictions with the value of this year's expected output of approximately $3.7 billion in components of all types, including $50 million worth of packaged assemblies and $35 million worth of planar and molectronic circuits.

"I feel strongly that there will continue to be a place in the evolution of electronic circuits for the less spectacular but vitally important work of the component development engineer, and the smaller and more reliable components which he will make possible," Mr. Sprague declared.

But the EIA Director cautioned, "it is also imperative that a component manufacturer acquire, if he does not already have it, competence in thin-film and semiconductor technology." . . . **The AM/FM Broadcast Section of EIA has prepared an up-to-date chronological record of all Federal Communications Commission proceedings on AM stereo.** The study was "in no way to be construed as support for AM stereo by the Section, but rather was merely to have such information available should the Section have to be prepared to take a position on the subject at a later date," said Section Chairman A. Prose Walker. EIA last January decided to undertake a study of AM stereo proposals to determine whether it should prepare a formal proposal to the FCC. An AM Stereo Study Group chaired by C. J. Votava was established. A limited number of copies of "Chronological Record of AM Stereo Proceedings" is available from the Industrial Electronics Division, EIA Headquarters.

ENGINEERING

A new bibliography on electronic miniaturization with 158 foreign and domestic references has been published by the Office of Technical Services, U. S. Department of Commerce. The bibliography covers research on micro-module production programs; resistor, diode and capacitor microelements; electron-beam-activated machining; ultrasonic grinding techniques in microminiaturization; thin film circuits; reliability and environmental testing; and microjunction formation technology. Listed are reports of the Army, Navy, Air Force, Atomic Energy Commission, and other Government agencies plus translations of foreign technical literature. All material listed in the bibliography is available from OTS. The bibliography, SB-444 "Electronic Miniaturization," (Supplement to CTR-250) may be ordered from OTS, U. S. Department of Commerce, Washington 25, D. C. Price 10 cents.

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* The data on which these NOTES are based were selected by permission from *Weekly Report* issues of May 7 and 14, 1962, published by the Electronic Industries Association, whose helpfulness is gratefully acknowledged.

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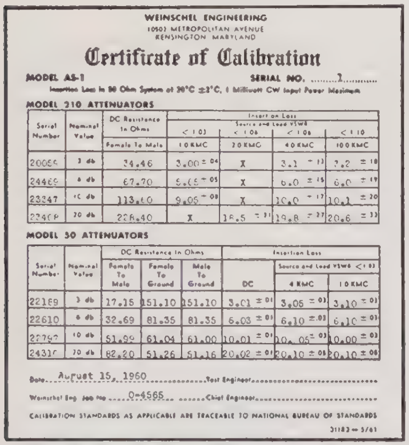

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Serial Number	Nominal Value	DC Resistance In Ohms	Insertion Loss			
			Source and Load VSWR			
			< 1.03	< 1.06	< 1.06	< 1.10
		Female To Male	1.0 KMC	2.0 KMC	4.0 KMC	10.0 KMC
20059	3 db	34.46	3.00 ±.04	X	3.1 ±.13	3.2 ±.18
24469	6 db	67.70	6.05 ±.05	X	6.0 ±.15	6.0 ±.19
23347	10 db	113.60	9.05 ±.08	X	10.0 ±.17	10.1 ±.20
22408	20 db	228.40	X	18.5 ±.31	19.8 ±.27	20.6 ±.33

MODEL 50 ATTENUATORS

Serial Number	Nominal Value	DC Resistance In Ohms			Insertion Loss		
						Source and Load VSWR <1.03	
		Female To Male	Female To Ground	Male To Ground	DC	4 KMC	10 KMC
22189	3 db	17.15	151.10	151.10	3.01 ±.01	3.05 ±.03	3.10 ±.03
22610	6 db	32.69	81.35	81.35	6.03 ±.01	6.10 ±.03	6.10 ±.03
22797	10 db	51.99	61.04	61.00	10.01 ±.01	10.05 ±.03	10.00 ±.03
24310	20 db	82.20	51.26	51.16	20.02 ±.01	20.10 ±.05	20.10 ±.06

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IRE People

Lucien E. Rawls (S'45–A'47–M'55), Director of the Leesburg Division, has been elected Senior Vice President of DECO Electronics, Inc., Washington, D. C., and Leesburg, Va. and **William S. Alberts** (A'41–M'44–SM'52) Associate Director of the Leesburg Division, has been elected a Vice President.

L. E. Rawls

W. S. Alberts

Mr. Rawls will continue as Director of the Leesburg Division and will technically direct DECO's advanced programs on Survival Communications. Since joining DECO in 1958, he has directed investigations of command and control systems for the Minuteman missile program and has directed extensive studies of practical systems under nuclear environment. He has also directed the DECO-sponsored substrata research program which demonstrated the first practical transmission of teletypewriter messages through rock formations. Prior to joining DECO, Mr. Rawls was Supervisor of Research and Development for WSM, Inc., where he directed the engineering of high-power transmitters, antennas, and switching systems.

Mr. Alberts, who joined DECO in 1956 as Assistant Technical Director, will also continue as Associate Director. He has served as Associate Project Engineer in the design of the radiation system for the Navy's VLF Transmitting Facility at Cutler, Maine, and as Project Manager for the development of improved shipboard communications antenna systems for the Navy. In addition, he participated in the design of the Air Force's ionospheric probe for the Arecibo radio observatory in Puerto Rico and in the Survival Communications Programs and subsurface programs. He is currently in charge of the DECO Electronics, Inc., effort in the design of a new superpower, VLF transmitting facility for the U. S. Navy in the Pacific area. Prior to joining DECO, Mr. Alberts was director of the General Engineering Department of Crosley Broadcasting Corporation.

❖

Franklin H. Blecher (S'49–A'53–M'58), Director of the Carrier Transmission Laboratory, Bell Telephone Laboratories, Inc., North Andover, Mass., has been named Chairman of the 1963 International Solid-State Circuits Conference, Feb. 20–22, on the campus of the University of Pennsylvania and at the Sheraton Hotel, Philadelphia, Pa.

S. K. Ghandhi (S'49–A'52–SM'56), Manager of the Electronic Component and Functions Laboratory, Philco Scientific Laboratory, Blue Bell, Pa., will serve as Chairman of the Technical Program Committee.

Lewis Winner (M'47), Technical Relations Consultant, has been reappointed Chairman of the Public Relations Committee.

The 1963 Conference Secretary will be **Francis J. Witt** (S'52–A'54–M'57), Supervisor of the Satellite Communications Laboratory, Bell Telephone Laboratories, Inc., Murray Hill, N. J. **Adolph K. Rapp** (M'56), Group Supervisor, Electronic Components and Functions Laboratory, Philco Scientific Laboratory, Blue Bell, Pa., will be Technical Program Committee Secretary.

Robert Mayer (SM'59), Sun Oil Co., Newtown Square, Pa., continues as Treasurer.

International arrangements will be under the supervision of **Tudor R. Finch** (M'56), Bell Telephone Laboratories, Inc., Murray Hill, N. J. **Veikko R. Saari** (A'52–M'60), Bell Telephone Laboratories, Inc., will serve as Editor of the Digest.

Murlan S. Corrington (SM'49–F'54) RCA, Camden, N. J., will continue as chairman of the sponsors advisory committee.

The conference is sponsored by the IRE, AIEE, and the University of Pennsylvania.

❖

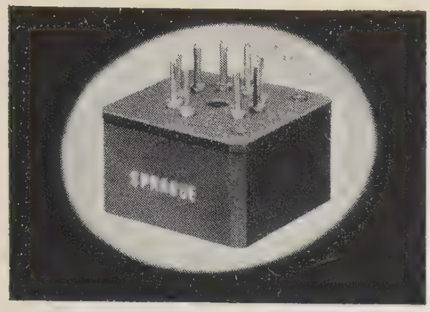
Dr. Gunther U. Sorger (M'55) has been appointed Director of Research at Weinschel Engineering, Kensington, Md.

G. U. Sorger

In his new position, Dr. Sorger will be in charge of an expanding program of research to advance the art of precise measurements in the microwave field. He has been with Weinschel Engineering since 1954 and has served as Head of the Standards Measurement Development Section where he was responsible for the development of many of the precision instruments which the firm now produces. Dr. Sorger is also an Adjunct Professor of Engineering at the Center for Measurement Sciences of George Washington University where he

(Continued on page 40A)

Magnetic Shift Registers Now Available At Sensible Prices



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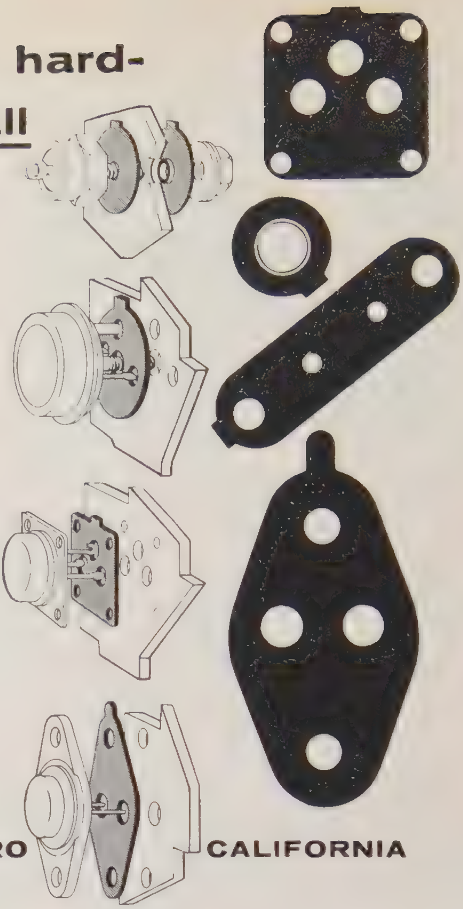

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IRE People

(*Continued from page 38A*)

teaches courses in microwave measurements. He is the author of many technical papers and has presented several of these to professional groups.

A member of the ISA, Dr. Sorger holds a Ph. D. degree in physics from the Technische Hochschule, Stuttgart, Germany, where he served as an Instructor for Communications Engineering before joining Weinschel Engineering.

❖

Mr. O. F. Hamann (S'47–A'49) has been named Director of Applied Research for Transdata, Inc., El Cajon, Calif.

Transdata, Inc. is an electronics research and manufacturing company which specializes in printers and display subsystems for advanced computer and communications systems.

❖

Charles R. Glaviano (M'57) has been appointed Regional Manager in the Government Relations Department of the Military Products Division, Adler Electronics, Inc., New Rochelle, N. Y. He will service U. S. Air Force establishments in Rome, N. Y. Prior to joining Adler he was Northeast Regional Manager for Hoffman Electronics Corp.

He is the IRE Section Arrangements Chairman, and Vice Chairman of the Professional Group on Communications Systems in the Rome-Utica area.

❖

J. J. Farrell

John J. Farrell (A'43–SM'47–F'48) who joined the General Electric Company as an apprentice trainee nearly 50 years ago, retired in March, 1962 following a career of distinguished achievement, particularly in the field of military electronics.

He was consultant to Dr. George L. Haller, General Electric Vice President and General Manager of the Company's Defense Electronics Division, at the time of his retirement.

Mr. Farrell is an active participant in many projects in the Syracuse Metropolitan Area. His range of community interest is exemplified by some of the various groups in which he participates. He is a member of the Board of Advisory Regents of Lemoyne College, the Onondaga County Water Committee, the Board of Directors of the American Red Cross, Catholic Charities, the Syracuse Chamber of Commerce and the new Community Hospital.

Until his appointment as consultant in May, 1961 Mr. Farrell had served as the only General Manager of the Heavy Military Electronics Department since its establishment in November 1953.

Mr. Farrell's career with General Electric began in 1913 in Schenectady following his graduation from high school in Watervliet. He was enrolled in the Company's four-year drafting apprentice training program.

Subsequently, he worked as a draftsman and later was named Supervisor of Drafting for the company's Radio Department. This was a period of rapid development in the radio field and considerable pioneering work was accomplished under Mr. Farrell's direction. Many of the standards then established served as a guide to what has now become the electronics industry.

In 1938, he was appointed Design Engineer in the Transmitter Department of the Electronics Division and six years later Division Engineer.

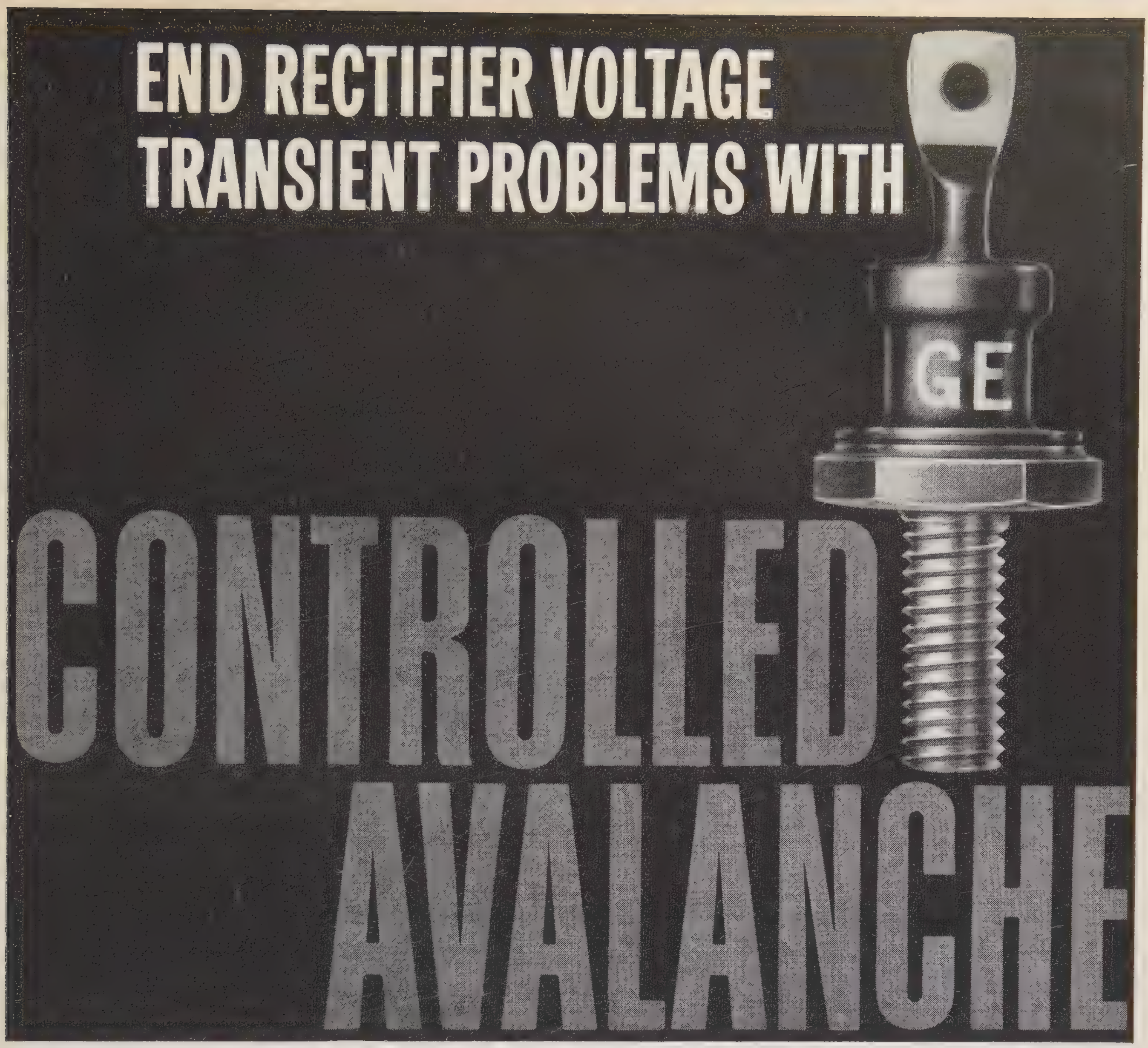
During World War II, Mr. Farrell was in charge of all electrical and mechanical engineering in the Transmitter Department. Extensive developments were achieved during this period in radar and sonar, automatic tracking fire control communications, countermeasures and proximity fuses.

In recognition of his contributions, Mr. Farrell was awarded a Certificate of Commendation by the U. S. Navy Bureau of Ships.

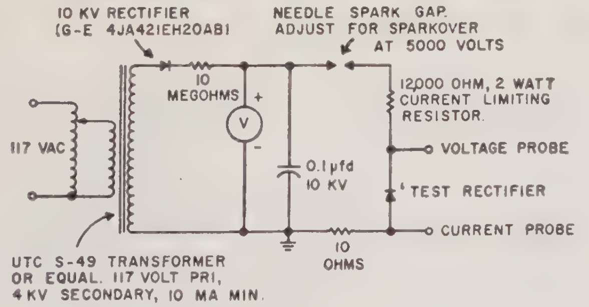
He also had an active part in the establishment of the joint Army-Navy standards of electronic components, designed to

(*Continued on page 42A*)

END RECTIFIER VOLTAGE TRANSIENT PROBLEMS WITH CONTROLLED AVALANCHE



The revolutionary 12 amp ZJ218 Controlled Avalanche Rectifier protects itself and the rest of the circuit up to 3900 watts peak power dissipation in the reverse direction. You get new high reliability standards up to 1200 PRV, protection of other circuit components, simplified rectifier series operation in high voltage applications, continuous operation in avalanche breakdown region at high voltage, and built-in "zener" diode protection even well beyond 1200 volts.


10 KV RECTIFIER
(G-E 4JA421EH20AB1
NEEDLE SPARK GAP.
ADJUST FOR SPARKOVER
AT 5000 VOLTS
10
MEGOHMS
+
V
-
12,000 OHM, 2 WATT
CURRENT LIMITING
RESISTOR
117 VAC
0.1 µfd
10 KV
VOLTAGE PROBE
TEST RECTIFIER
CURRENT PROBE
10
OHMS
UTC S-49 TRANSFORMER
OR EQUAL. 117 VOLT PRI,
4 KV SECONDARY, 10 MA MIN.

This reverse impulse test will prove how the Controlled Avalanche Rectifier withstands typical transient circuit voltages as high as 5000 volts, dissipates high levels of peak power in the reverse direction. Peak reverse power for rectifiers with avalanche voltages above 800 volts is over 250 watts in this circuit. (Connect a scope between the indicated voltage and current taps and ground to view impulse voltage and current.)

TEST IT YOURSELF . . . and prove beyond any doubt that your derating headaches are a thing of the past, that your transient voltage problems are solved more efficiently, more economically than ever before possible. The Reverse Impulse test circuit shown is all you need . . . along with the new G-E ZJ218 Controlled Avalanche Rectifier.

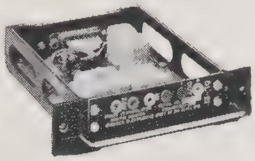
The ZJ218 Controlled Avalanche Rectifier is available in 600, 800, 1000 and 1200 PRV types. See your General Electric District Sales Manager and find out how to end *your* voltage transient problems with no derating. Or write Rectifier Components Department, Section 23G74, General Electric Company, Auburn, New York. In Canada: Canadian General Electric, 189 Dufferin Street, Toronto, Ontario. Export: International General Electric, 159 Madison Avenue, New York 16, New York.

GENERAL ELECTRIC

NOW

HIGH PRECISION
LOW LEVEL
PCM SIGNAL
CONDITIONING
SYSTEMS

This phase demodulator is typical of modules being designed and built by Dresser Electronics/SIE Division for signal-conditioning applications throughout military and industrial areas. The recently-completed high-precision PCM system, of which this module is a part, is one of the first air-borne, low-level systems proven by use.



PCM PHASE
DEMODULATOR

Input: 0-12 microamperes, 800 c-p-s

Output: 0-40 millivolts, d-c, with 0.5% max. ripple

Accuracy: Max. deviation from linear 0.5% of full scale for combined effects of linearity, zero-point shift and gain shift

Stability: Max. output variation 0.5% of full scale/hour

YOUR
SPECIFICATIONS
BRING AN
IMMEDIATE
QUOTE

DRESSER ELECTRONICS
SIE DIVISION/A DIVISION OF DRESSER INDUSTRIES, INC.
10201 WESTHEIMER, HOUSTON 42, TEXAS

IRE People

(Continued from page 40A)

ease problems of procurement and supply. For his efforts, he received a Certificate of Contribution to American War Standards awarded by the American Standards Association.

Following the war, Mr. Farrell had complete engineering responsibility for the Commercial and Government Equipment Department which developed a complete line of commercial transmitters and communications products.

With increased need for military equipment in the Korean War, the company established the Heavy Military Electronics Department with Mr. Farrell as General Manager. Under his guidance, the department became a leader in the development and production of military electronic equipment.

In 1960, Lemoyne College awarded him an honorary degree of Doctor of Humane Letters for his "organizing ability and professional knowledge in helping to harness the powers of industry and technology to the service of his country."

Mr. Farrell is a licensed professional engineer in New York State and is the author of several technical papers published in engineering and scientific publications.

He was appointed a Fellow in the Institute of Radio Engineers for "contributions to the design of radio and radar transmitters, and for his leadership in the establishing of industry standards."

He is a former Chairman of the Transmitter Section of the Radio-Electronic Industries Association, a member of the Scientific Research Society of America and the New York State Professional Engineers Society, the Century Club and Rotary.

He is a former member of the board of directors of General Electric's wholly-owned European subsidiary, Apparatenindustrie Defense Electronics located in The Hague, Netherlands.

⁂

Dr. Emanuel R. Piore (A'38–M'42–SM'43–F'50) has been named a member of the Corporate Management Committee of International Business Machines Corporation. Dr. Piore will continue to direct the company's scientific and technological efforts as Vice President, Research and Engineering.

E. R. Piore

The former chief scientist of the Office of Naval Research joined IBM in 1956 as Director of Research. He was elected Vice President, Research and Engineering, in 1960.

Dr. Piore is a member of the President's Science Advisory Committee and the Visiting Committee of the Department of Physics of Harvard College.

⁂

Two new directors were elected to the board of the General Radio Company at the recent annual meeting: **Ivan G. Easton** (S'39–A'41–SM'45–F'60), Vice President for Engineering, and **Harold M. Wilson** (SM'46), Vice President for Manufacturing.

I. G. Easton

H. M. Wilson

⁂

J. Walton Colvin (M'51) has been named Manager of Plans and Programs for General Dynamics/Electronics, San Diego, Calif.

Mr. Colvin, who had been with the Bendix Corporation since 1942 in various marketing executive positions, will be responsible for marketing GD/E's radar electronic and data processing product lines.

With the Bendix Field Engineering Corporation, he was Manager of Marketing. Earlier with the Radio Division, he was Director of Requirements Research and Planning, Manager of Market Research, Manager of Government Sales and Merchandising Manager.

J. W. Colvin

During World War II, he served as technical advisor to the Commanding General of the U. S. Army Air Force in the Mediterranean theatre.

For the past two years Mr. Colvin was President of the Baltimore Chapter of the American Marketing Association. Previously he was President of the Armed Forces Communications and Electronics Association. In addition, he is a member of the Air Force Association, Association of U. S. Army, and National Aviation Club, Washington, D. C.

⁂

John E. Ebert (J'41–A'43–SM'53) has been named Vice President in charge of Research, Development and Engineering of Weinschel Engineering Co., Inc., Kensington, Md.

Mr. Ebert came to Weinschel Engineering with twenty years' experience in the microwave field. For the last nine years he was with FXR, Inc., Woodside, N. Y. as Vice President and Chief Microwave Engineer. While at FXR, Mr. Ebert was responsible for the design, development and other engineering aspects of FXR's proprietary line of microwave and electronic test equipment.

Mr. Ebert was graduated from the Polytechnic Institute of Brooklyn in 1947 with a Bachelor's degree in Electrical

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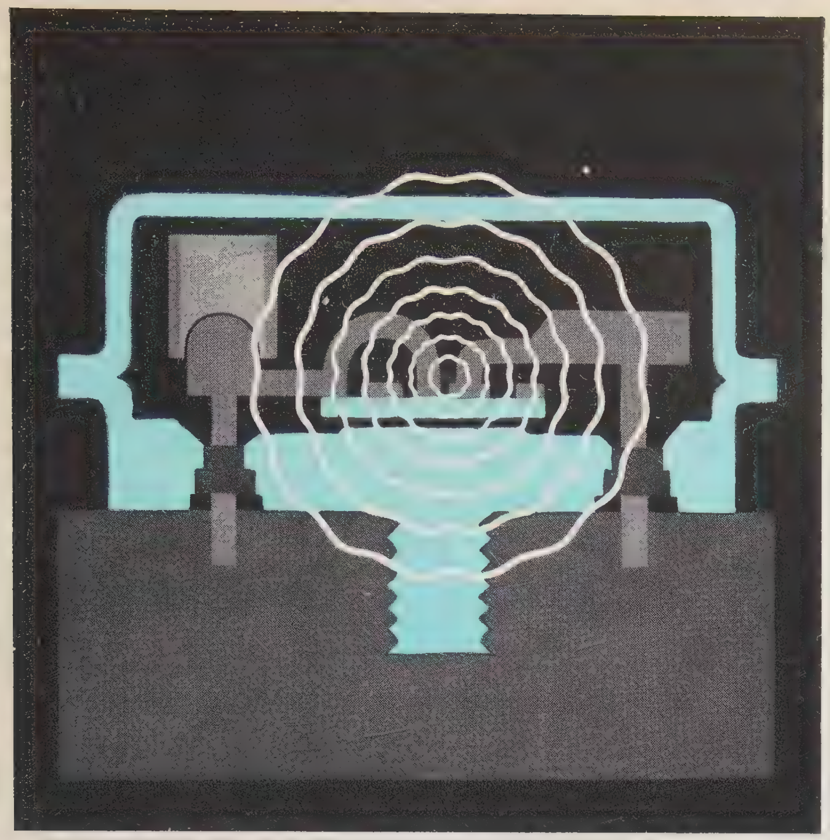

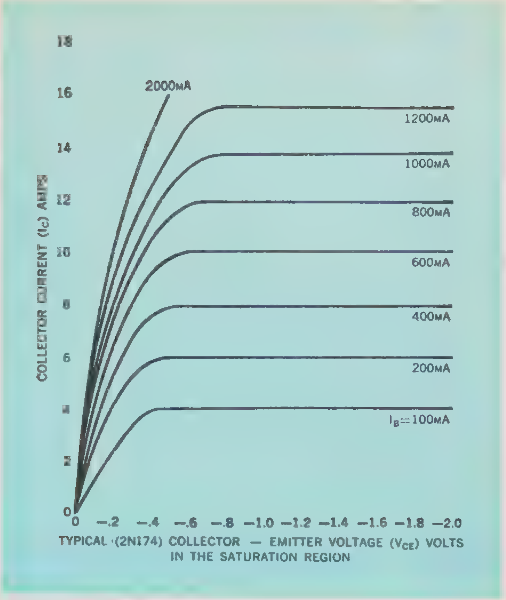
18
16
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COLLECTOR CURRENT (Ic) AMPS
2000MA
1200MA
1000MA
800MA
600MA
400MA
200MA
I_B=100MA
0
−.2
−.4
−.6
−.8
−1.0
−1.2
−1.4
−1.6
−1.8
−2.0
TYPICAL (2N174) COLLECTOR — EMITTER VOLTAGE (V_{CE}) VOLTS IN THE SATURATION REGION

Saturation voltage V_{CE} (sat) is an extremely important transistor characteristic. When the collector to base voltage of a transistor is either zero or in the forward direction and the emitter to base voltage also is in the forward direction the transistor is said to be in saturation. Low saturation voltage improves circuit efficiency and reduces transistor dissipation in applications in which the transistor is driven into saturation. This results in lower junction temperature and improved temperature stability.

TUNG-SOL MINIMIZES V_{CE} (sat)

TO PRODUCE POWER TRANSISTORS THAT DELIVER FULL POWER

Power transistors can be rated by at least a score of characteristics. For most of these, the ratings of an ordinary transistor may be equivalent to the ratings of a Tung-Sol transistor—*under optimum conditions.*

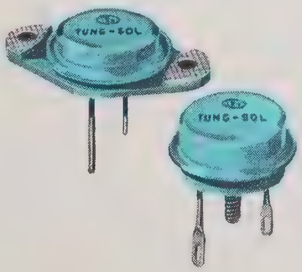
But Tung-Sol engineers have long recognized that power transistors are rarely operated under the so-called optimum conditions. Circuit requirements vary widely and so do operating environments. A better measure of power transistor quality and capability are the characteristics which contribute to transistor reliability and performance under less-than-optimum conditions.

One such characteristic is saturation voltage. Tung-Sol transistors are designed with the lowest possible saturation voltage consistent with other performance requirements.

Low saturation voltage results in lower transistor dissipation and lower junction temperature. This reduces the variation of the temperature dependent parameters of the transistor with resultant improvement in circuit and operational stability. Low saturation voltage decreases internal resistance and temperature and increases useful power-handling. Therefore, a low saturation voltage becomes increasingly important as the transistor is operated closer to its maximum power or in a high-temperature environment.

Low saturation design is typical of the care taken by Tung-Sol to provide the industry with transistors that reliably deliver full power. Ratings, based on stringent environmental and electrical tests, are given for junction temperatures of 110°C. Thermal resistance is low, while breakdown voltages are high.

Two more power pluses are Cold-Welded copper cases, for better heat dissipation and prevention of contamination, and flat-ground mounting surfaces, for full contact with heat sinks. Talk to Tung-Sol about your transistor problems. Tung-Sol Electric Inc., Newark 4, N. J. TWX:NK193.



TUNG-SOL® FULL POWER
POWER TRANSISTORS

IRE People

(*Continued from page 42A*)

Engineering. He is a member of Sigma Xi, Tau Beta Pi, and Eta Kappa Nu. He holds nine patents and is the author of a number of articles which have been published in professional journals.

❖

Gilbert and Felix, Inc., New York, announced the appointment of **Arthur P. Salsberg** (A'61) as Technical Director. In his new post, he will work closely with the agency's electronic accounts. Mr. Salsberg was formerly Managing Editor of *Electronic Technician* and *Industrial Electronic Engineering and Maintenance* magazines.

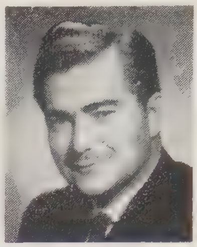
A. P. Salsberg

He brings both technical and editorial experience to the agency. Prior to his editorial position he was National Service Manager of Capitol Records' Phonograph Division; Electronics Instructor at Pierce School of Radio and Television; and Sales Manager of Authorized Appliance Corp.

Mr. Salsberg was graduated from the College of the City of New York and RCA Institute. His professional affiliations are the American Management Association and the Audio Engineering Society.

❖

Endevco Corporation, Pasadena, Calif., announced the appointment of **J. Richard Wilkins** (A'57) to the post of Assistant Contracts Administrator for the company's line of Piezoelectric Accelerometers and for the DC instruments manufactured by Endevco's Video Instruments Division.



J. R. Wilkins

Mr. Wilkins was formerly a field engineer with Hoffman Electronics Corporation, Los Angeles. Previous employment includes Philco and Lockheed. He began his electronic training at Great Lakes Navy Electronics School and continued at Georgia Institute of Technology.

❖

Electronic Communications, Inc., St. Petersburg, Fla., announced that **Vincent D. Carnevale** (S'54–A'55–M'58), who has been supervisor of field engineering under marketing, will become supervisor of field service engineering and will be assigned additional duties in line with the broadened scope of the function.

Mr. Carnevale, a graduate of RCA Institutes, has been with ECI since 1957, serving successively as test engineer, senior manufacturing engineer, supervisor of test facilities, engineering and, since March, 1960, as supervisor of field engineering. He is a member of the American Society of Quality Control.

❖

H. Gunther Rudenberg (S'41–A'45–M'51–SM'57) has joined Arthur D. Little, Inc., as a member of the senior staff of the Research and Development Division. In this post Dr. Rudenberg will be concerned with the development of the new generation semiconductor devices, and related research and engineering problems.

H. G. Rudenburg

Previously, Dr. Rudenberg, who holds a Ph.D. degree in physics from Harvard University, was Director of Research at Transitron Electronic Corporation, a post he held since the founding of the firm in 1952.

Active in IRE affairs, Dr. Rudenberg is 1962 Chairman of the Northeast Electronic Research and Engineering Meeting. He was formerly Chairman of the IRE Boston Section.

❖

Donald C. Bright (SM'49) has recently joined Zenith Radio Corporation as Director of the Government and Special Products Division.

In this new Zenith post, Mr. Bright will direct the company's marketing activities in the government and special products field. He will also be responsible for production schedules for special products contracts, for liaison with the company's engineering and production divisions, and will work closely with the government and special product activities of Zenith subsidiaries.

D. C. Bright

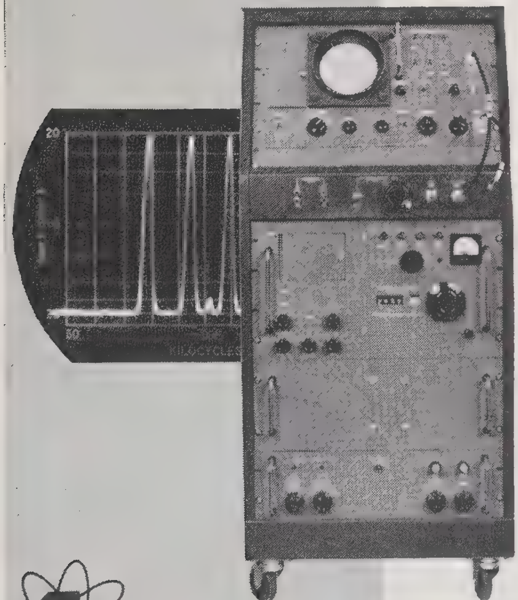
Prior to joining Zenith, he was Vice President and Director of Marketing of Hoffman Electronics Corporation's Instrument-Industrial Division, Los Angeles.

From 1955–1959 Bright served as Sales Manager of the Missile and Surface Radar Division of the Radio Corporation of America, in Van Nuys, Calif. and earlier served the firm as Manager of Air Force Sales and Sales Manager of Microwave and National Accounts Mobile.

He was chief of the Radio Section for guided missiles at Wright Field, Dayton, Ohio, during World War II. Later, he served as Chief Engineer for the Liberty Manufacturing Company (formerly Areo-Rad Corp.).

A graduate of the University of Pitts-

(*Continued on page 46A*)



PTE-3
AN/GRM-33A

SINGLE SIDEBAND ANALYZER

TMC Model PTE-3 is a multi-purpose test instrument used at communication facilities, labs, and electronic production plants for visual analysis of RF signals from 1.5 to 64.5 Mcs.

The PTE-3 is used for tuning and aligning transmitters, sideband exciters, RF filters, and for band occupancy studies. Detailed analysis of any portion of the selected spectrum for intermodulation distortion, harmonic distortion, sideband suppression, carrier suppression, etc., is made possible by a manual sweep control.

The PTE-3 contains a variable frequency oscillator with long-term stability, and an audio and RF tone generator for distortion analysis and internal system test.

The Test Equipment Division Of
THE TECHNICAL MATERIEL CORPORATION
World Wide Suppliers of Electronic Communications Equipment
and Subsidiaries MAMARONECK, NEW YORK
OTTAWA, CANADA•ALEXANDRIA, VIRGINIA•GARLAND, TEXAS•LA MESA, CALIFORNIA•POMPANO BEACH, FLORIDA

NOW
½ μSEC CAPABILITY
IN RCA'S
COMPLETE, INTEGRATED
MEMORY PRODUCT LINE

RCA adds new ultra-high-speed, low-drive Microferrite Stacks to its full, integrated line of memory components.

New 0.5 μsec Microferrite Word-Address Memory Stacks: RCA's new Microferrite Memory Stacks make possible complete read/write cycle times of less than 0.5 μsec at driving currents no higher than 350 ma with at least 50 mv output. This revolutionary new stack, designed to meet Military Specifications, is a result of RCA's broad experience in producing thousands of memory planes and stacks in hundreds of configurations.

Versatile RCA Memory Planes and Stacks: In addition to the new Microferrite Word-Address Memory Stack, RCA's broad line includes: Wide temperature range stacks incorporating temperature stable, high-temperature ferrite cores...Temperature controlled stacks designed to meet MIL Specifications...Conventional memory stacks without temperature controls for applications requiring high quality at lowest possible price. All RCA planes and stacks are 100% dynamically tested to assure compliance with operating specifications. Planes are available in molded plastic, printed circuit and aluminum frames.

Wide-Margin Ferrite Cores — High-Speed Transfluxors: RCA offers one of the industry's most comprehensive lines of memory cores all designed with specified wide operating margins. One of the newest additions to the line is type 233 M1, a high-temperature core having an output variation less than 0.25 mv per °C over a 140°C temperature range. RCA memory transfluxors are available with switching speeds as fast as 1.3 μsec.

Field-Proved Complete Memory Systems: You can choose from a broad range of standard RCA types and custom designs to suit your needs. RCA is prepared to meet the tightest custom limits for voltage, current, temperature range and speed of operation to make each memory system compatible with your equipment.

Service: Today RCA Memory Products are in use in an ever widening range of commercial, industrial and military equipments...from high-speed printers, process controls, to military missile systems. Whatever your requirements, custom or RCA-standard, your local RCA Semiconductor and Materials Division field representative is prepared to provide a completely coordinated application service for all RCA Computer-Memory Products. Call him today. For specific technical information, write RCA Semiconductor and Materials Division, Commercial Engineering, Section FT7, Somerville, N. J.

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COMPONENTS AND DEVICES
RCA MEMORY PLANES
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Write today for information on RCA microferrite stacks and full line of Memory Products.

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The Most Trusted Name in Electronics

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(Continued from page 44A)

burgh with a Bachelor of Science degree in electrical engineering, Mr. Bright has done graduate work at the University of California at Los Angeles.

❖

ARDE Inc., recently announced the appointment of **Herbert E. Peitzer** (SM'58) as Vice President of the Engineering Divisions, Newark, N. J. and Huntsville, Ala. Mr. Peitzer will devote his efforts to the consultant engineering and design divisions, directing new research and development programs, sales, and the establishment of new regional offices. He was formerly manager of the ARDE Engineering Division, Newark, N. J. and joined ARDE in 1955 as a technical specialist in airborne structures.

H. E. Peitzer

Mr. Peitzer, who holds a B. Ae. E. Degree from New York University, is a member of the Institute of Aerospace Sciences, a member of the American Society of Mechanical Engineers and a member of the Society of Automotive Engineers. Before joing ARDE, he was associated with Republic Aviation, Gyrodyne Company of America and the National Advisory Committee for Aeronautics.

❖

John W. Winter (M'60) recently joined Aviation Instrument Manufacturing Corporation, Houston, Texas as Vice President, Engineering, where he will direct the research and development activities of their gyroscopic flight instruments and servo systems.

J. W. Winter

Mr. Winter was formerly with Aircraft Radio Corporation as Senior Project Engineer in the design and development of aircraft nav/comm and flight control systems. He holds a Bachelor's degree in electrical engineering from Rensselaer Polytechnic Institute and a Master's Degree in electrical engineering from Yale University. He is a member of the Yale Engineering Association, as well as the Tau Beta Pi and Eta Kappa Nu Fraternities.

❖

J. T. Williams

B. S. Parmet

John T. Williams (S'47–A'49–M'55), has been named Director of Engineering for the Hallicrafters Co., Chicago, Ill. He will be in charge of active electronic warfare, passive electronic warfare, digital techniques, antenna techniques and engineering services departments.

Bernard S. Parmet (SM'52), has been appointed Technical Director and will head up applied research and development and systems engineering activities.

Mr. Williams was promoted to Director of Engineering, Aerospace Division, from Manager of Passive Electronic Warfare Engineering. He joined Hallicrafters in 1955 after four years as Project Engineer at Sentinel Radio Corp. and three years as Design Engineer at Zenith Radio Corp. He is former Chairman of the Chicago Chapter of the IRE and an electrical engineer graduate of Purdue University.

Mr. Parmet joined Hallicrafters in July, 1959, as Chief Scientist for Reconnaissance Engineering and became Technical Director of the Government Section before assuming his present duties as Technical Director for the Aerospace Division. He was formerly with the Military Electronics Division of Motorola, Inc., in Phoenix, Ariz., and Chicago television station WBKB. He holds both B.S. and M.S. degrees in electrical engineering from Illinois Institute of Technology.

❖

The appointment of **Dr. Julien Keilson** (SM'56) as a Senior Scientist of Sylvania Electric Products Inc. has recently been announced.

Dr. Keilson joined the staff of the Applied Research Laboratory in 1956. Since that time he has conducted studies on theoretical aspects of electronic countermeasures, radar countermeasures, queuing theory techniques, and most recently the physics associated with vehicle re-entry into the earth's atmosphere.

J. Keilson

He received his Bachelor's degree in physics from Brooklyn College and his Master's and Doctor's degrees in physics from Harvard University. He was an Atomic Energy Commission pre-doctoral Fellow in electronics at Harvard.

Prior to joining Sylvania, Dr. Keilson was with the Lincoln Laboratory of the Massachusetts Institute of Technology where he worked on diffusion and noise problems with application to radar and communications systems.

He is a fellow of the Royal Statistical

(Continued on page 48A)

WHICH DEFLECTION YOKE FOR YOUR DISPLAY ?

Consult SYNTRONIC

YOKE SPECIALISTS

Syntronic's team of experts knows more about yoke design, engineering and quality control than anyone else. A solid 10-year record of leadership—acknowledged throughout the industry. Benefit from it.

syntronic INSTRUMENTS, INC.
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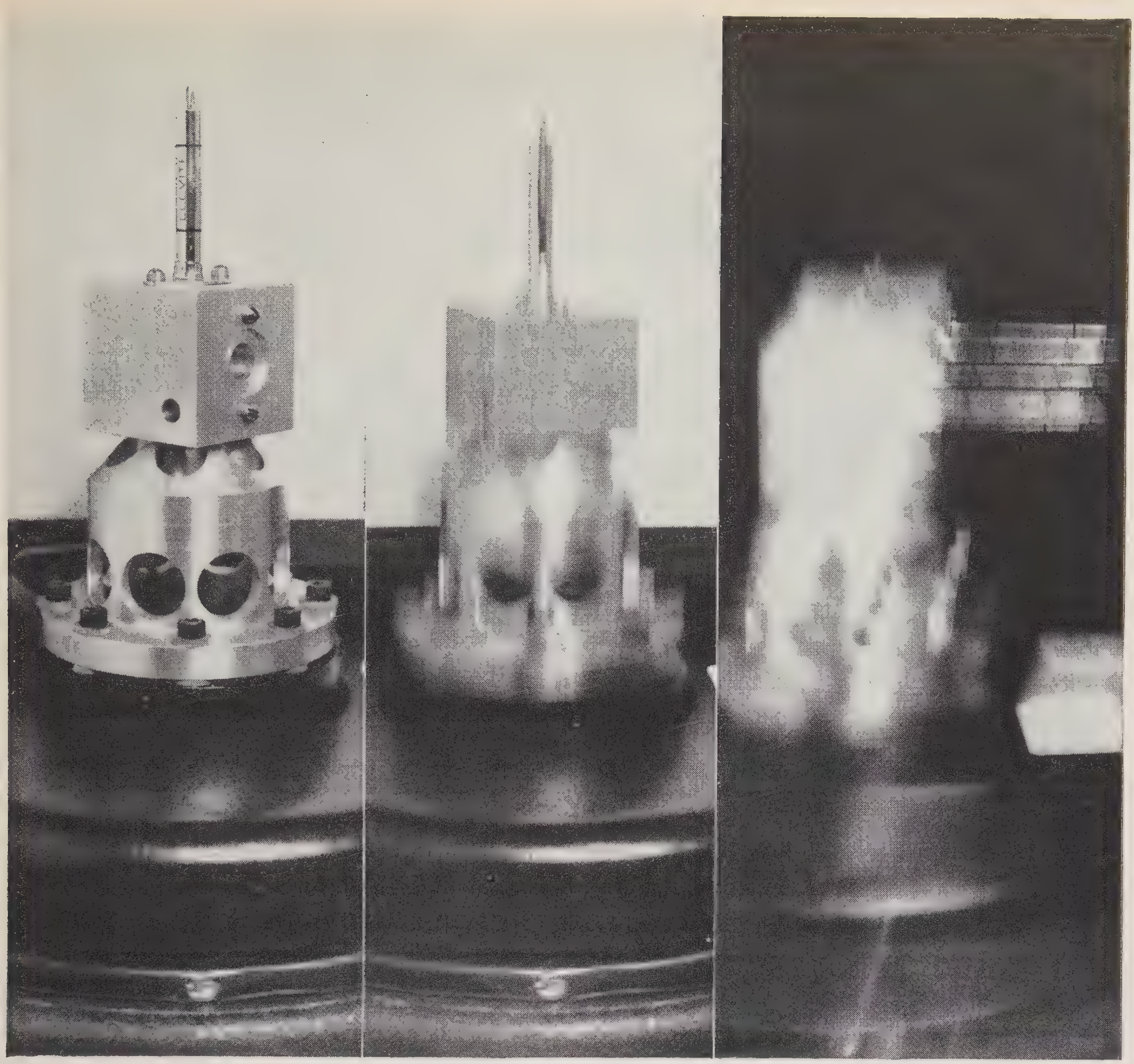
Phone: Kingswood 3-6444



Specify proven stability

with CLEVITE Ceramic Filters

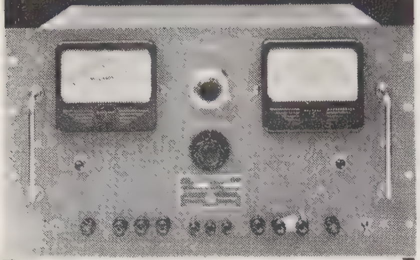
Does your i-f filter maintain center frequency under vibration and shock? It does if it's a Clevite ceramic ladder filter. Center frequency shift is negligible after MIL 202B shock and vibration tests*. ■ Stability like this is worth considering whether your next receiver is ground or airborne. Clevite now stocks 455 kc and 500 kc ladder filters in 12 bandwidths from 2 kc to 50 kc. Standard models pack 80 db stopband rejection into a 0.1 cu. in. package. ■ Write or phone the nearest Clevite office for immediate information, prices and delivery on Clevite ceramic ladder filters.

*actual test plots on request.

Field Sales offices: New York, New York/Chicago, Illinois/Denver, Colorado/Inglewood, California.

CLEVITE
ELECTRONIC
COMPONENTS
DIVISION OF CLEVITE CORPORATION
232 FORBES ROAD, BEDFORD, OHIO

ELECTRONIC MEASUREMENTS
high-precision
POWER SUPPLIES



the power supplies demanded by the laboratory

There are a lot of reasons why E/M's high-precision power supplies are in such demand by R & D laboratories. Ten-turn main DC control and vernier provide high resolution of output voltage from just a few millivolts to 1000 V DC, depending on model. Regulation is at least 0.02%. And full current output is available at any voltage . . . even at less than one volt. Various models cover current ratings up to 1.5 A. Some models feature a −150 V bias output. Others include a modulation input. All models have a 6.3 V AC CT output. And there are still more features . . . fully described in Catalog VR 1962.

ELECTRONIC MEASUREMENTS
COMPANY, INCORPORATED
EATONTOWN · NEW JERSEY

IRE People

(Continued from page 46A)

Society, a member of the American Physical Society, and the American Institute of Mathematical Statistics. He is the author of numerous technical papers and is currently a lecturer at Massachusetts Institute of Technology.

⁂

Col. James H. Davitt (SM'57), USA (Ret.) has been appointed to the Senior Engineering Staff of General Electronic Laboratories, Cambridge, Mass.

J. H. Davitt

Col. Davitt joined GEL after more than twenty years service in the Army Signal Corps in both Staff and Line positions. He is a past national Vice Chairman of the IRE Professional Group on Military Electronics.

A graduate of the University of Illinois with a B.S. degree in chemistry, Col. Davitt also received an M.S. degree in science from the same University.

Highlights of his Army Career include assignments as: Chief, Research and Development Division, Signal Office, U. S. Army Ordnance Missile Command; Assistant Director, Surveillance Department, U. S. Army Signal Research and Development Laboratory; Director, Project MONMOUTH, USASRDC. During the Korean War Col. Davitt served as Division Signal Officer, 24th Infantry Division, and as Commander, 101st Signal Battalion, IX Corps, Korea. During World War II Col. Davitt served in North Africa and Europe.

⁂

Airborne Instruments Laboratory a division of Cutler-Hammer, Inc., announced the appointment of **Karle S. Packard, Jr.** (M'50–SM'56), as Head of AIL's Reliability Department.

K. S. Packard, Jr.

Mr. Packard received his A.B. degree in physics from Columbia University in 1943 and his M.S. degree in physics from New York University in 1951.

During 1943 and 1944 Mr. Packard was a staff member of the Division of War Research of Columbia University, where he worked on magnetometer sensitivity; sources of noise in the magnetic airborne detector for submarine detection; and the development of receivers for jamming equipment. From 1944 to 1946 he was with the National Carbon Company, where—until the end of the war—he worked on the development and production engineering of reserve energizers for proximity fuzes. Later, he worked on dielectric heating techniques for thermoplastic materials.

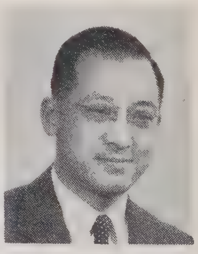
In 1946 Mr. Packard joined AIL. He has served as project engineer on the development of stereoscopic cathode-ray tube displays, on the development of magnetic survey equipment for oil prospecting, and on advanced developments for magnetic airborne detection equipment. He has been responsible for the development of a video recording and reproducing system using flying-spot-scanner techniques; for the development of a microwave remote link; for the development of automatic SWR and impedance plotters; and for the development of various antennas and microwave systems and components—particularly the application of strip transmission line. He has also done theoretical work on the use of tropospheric scatter-propogation. Most recently he has been engaged in organizing and providing technical and administrative direction for activities concerned with product reliability.

In 1955 Mr. Packard was appointed Consultant to the Special Systems and Components Department of AIL, in 1958 he was made Manager of the Reliability Section of the Department of Space Technology and Advanced Research, and in 1960 he was appointed Consultant to the Research and Systems Engineering Division. In 1962 AIL's reliability activities were expanded and reorganized, and Mr. Packard was appointed Department Head of the Reliability Department.

Mr. Packard is a member of the American Physical Society and AAAS. Since 1954 he has served on the Antennas and Waveguides Committee of the IRE, and in 1958–1959 he served as chairman of the Long Island Chapter of the Professional Group on Microwave Theory and Techniques. He is the author of numerous technical papers, largely in the fields of microwaves and reliability, and he is a contributing author of the "Antenna Engineering Handbook."

⁂

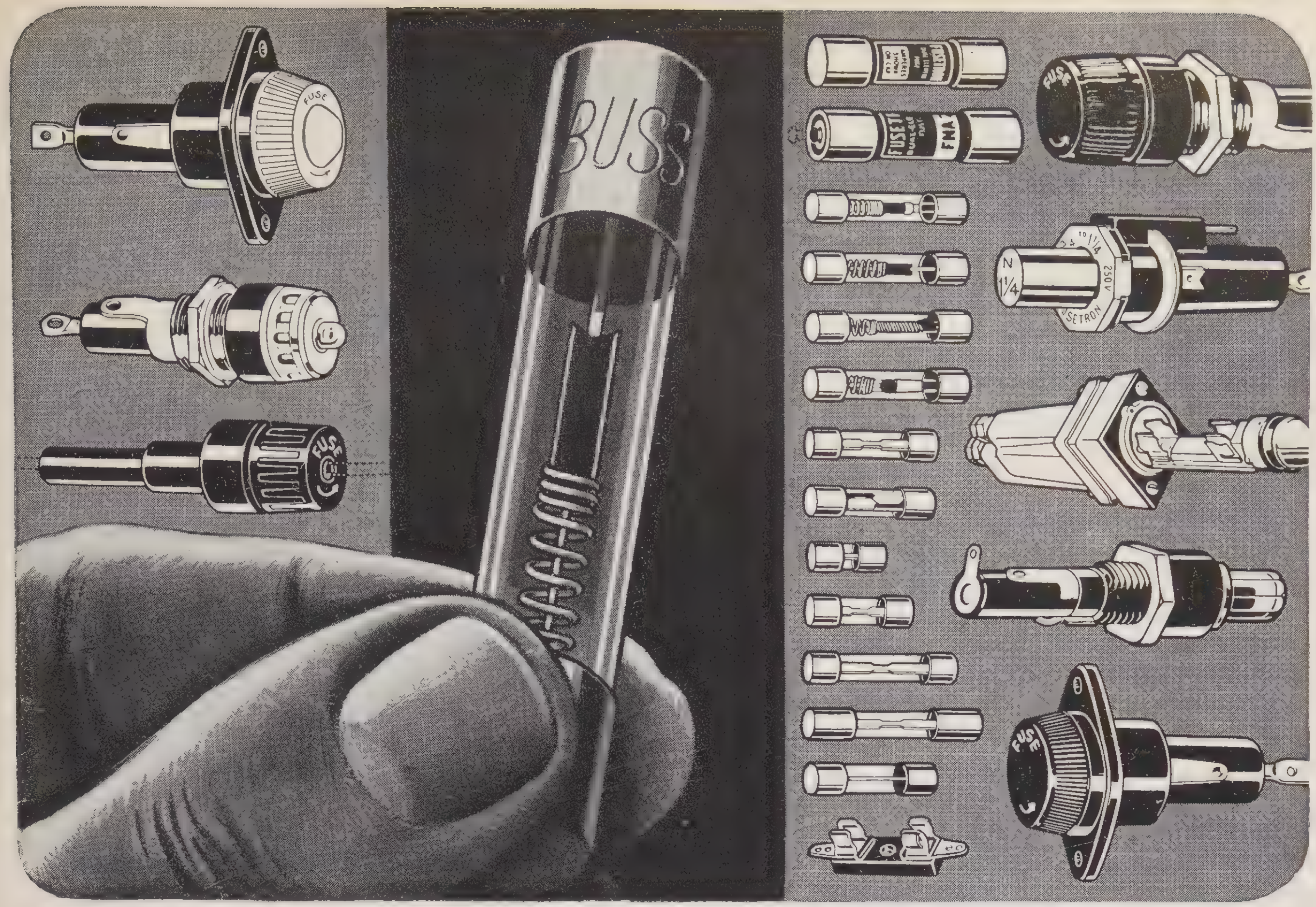
Wen Tsing Chow (S'42–A'45–M'49–SM'52) has been appointed Manager, Computer Products, for Arma Division, American Bosch Arma Corporation. In his new capacity, Mr. Chow will be responsible for the management and planning of all computer activities at Arma, including liaison with the American Bosch Arma Corporation marketing staff.



W. T. Chow

Prior to his appointment, Mr. Chow was Program Manager of the Arma inertial guidance system for Air Force Atlas ICBMs. He was

(Continued on page 50A)



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IRE People

(Continued from page 48A)

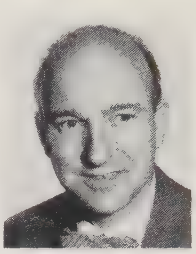
instrumental in the design of the digital computer for that system.

Before joing Arma in 1951, Mr. Chow was associated with General Electric Company and held instructorships at Massachusetts Institute of Technology and New York University. He is a graduate of Chiao Tung University, China, and holds an advanced degree from M.I.T.

⁂

Cubic Corporation recently appointed **Glenn A. Walters** (SM'58) to the post of Vice President, Product Research.

Previous to his joining Cubic, Mr. Walters was a Vice President for the Dalmo-Victor Company serving in the capacities of Director of Research and Manager of the Electronics Systems Division. Prior to moving into industry Mr. Walters was a research associate at Stanford University. A graduate of the University of California, he served during World War II as a Naval flier and in the technical capacity of the Research Laboratories of M.I.T. and Harvard University. Before entering the service he was Supervisor of a West Coast shipyard.



G. A. Walters

Walters has had sixteen years of managerial and engineering experience in research and development in the field of antenna systems, microwave componentry, magnetic devices, sonic systems, hydraulic mechanisms and communications. He has developed numerous advanced electronics and electromagnetic designs for military equipment and holds many patents.

He has written several technical papers for the Proceedings of the IRE and other technical publications. He is currently Secretary of the Professional Group on Engineering Management and has served as Chairman in many of the WEMA and WESCON activities.

⁂

Dr. David A. Kahn (A'51–M'56) formerly Systems Research Department Manager of the Cornell Aeronautical Laboratory has been named by Melpar, Inc., to the newly created position of Systems Associate. In this capacity he will act as consultant to Melpar's technical groups and investigate new areas for the electronics firm's military systems expansion

At Cornell, Dr. Kahn headed a 100-man department which conducted research and development in advanced weapons systems, surveillance and target location systems, and optical and photographic technology.

High prority missile systems development in which Dr. Kahn played a major role during his thirteen years at Cornell includes the Army's LaCrosse missile, the Plato anti-missile system for which he was program manager, and Project Defender for Defense Department's Advanced Research Projects Agency.

In the fall of 1959 Dr. Kahn took time out to participate as a consultant in air defense studies conducted by the Supreme Headquarters of the Allied Powers of Europe, at The Hague, Netherlands.

From 1939 to 1949 Dr. Kahn was employed at the Curtiss Wright Corp., Buffalo, N. Y., and Columbus, Ohio, where he was in charge of electrical design and installation. He received his Ph.D. degree in electrical engineering from Ohio State University in 1948 and his M.S. and B.S. degrees in electrical engineering at Cornell University.

Dr. Kahn is a member of the Institute of Aerospace Sciences and the American Rocket Society. He has been elected to membership in the following honorary societies: Eta Kappa Nu, electrical engineering; Sigma Pi Sigma, physics; and Sigma Xi, research.

⁂

George Rappaport (A'41–M'44–SM'46–F'56) former Vice President of Emerson Radio and Phonograph Corporation and a veteran of fifteen years in top civilian electronics positions with U. S. government agencies, has been elected President and Chief Executive Officer of Warnecke Electron Tubes, Inc., new joint French-U. S. firm, Chicago, Ill.

G. Rappaport

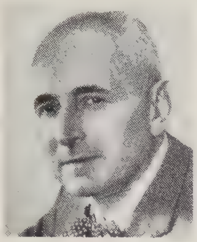
At Emerson, Mr. Rappaport also served as Vice President and Assistant to the President of Emertron, Inc., his responsibilities covering broad phases of engineering, manufacturing and marketing management.

With the Air Force at Wright Field, Dayton, Ohio, from 1944–1956, he was a leading pioneer in the electronic countermeasures field. Among the various scientific and management positions he held were Consultant to the Chief of the Weapons Guidance Laboratory, Chief of the Weapons Defense Branch, Chief of the Advanced Development Branch of the Reconnaissance Laboratory, and Chief of the Plans Staff.

Rappaport, 42, holds a Bachelor's degree in electrical engineering from the College of the City of New York and a Master's degree in electrical engineering from Ohio State University. He has done further graduate work at both Ohio State and the University of Michigan. He is a former member of the IRE board of directors, and a member of the National Security Industrial Association, Army Ordnance Association, Armed Forces Communications and Electronics Association, U. S. Navy League, and Air Force Association.

❖

The Army's Diamond Ordnance Fuze Laboratories, Washington, D. C., announced the appointment of **Dr. Henry P. Kalmus** (A'39–SM'45–F'56) as Chief Scientist, a new senior position in DOFL, under Public Law 313.


H. P. Kalmus

Dr. Kalmus was born in Vienna and received his training at the Technical University of Vienna. He was an Engineer with the Orion Radio Corporation, Budapest, the Emerson Corporation, New York, and joined the Zenith Radio Corporation, Chicago, in 1941. In 1948 he accepted a position with the Ordnance Electronics Division of the National Bureau of Standards. He has been an Associate Technical Director of DOFL since 1958.

Dr. Kalmus has written many technical papers and holds more than 30 patents in the field of electronics and applied physics. He is a member of the Washington Academy of Sciences, and recipient of the Gold Medal Awards for Exceptional Service from both the Department of Commerce and the Department of the Army.

❖

The appointment of **Edgar W. Harrington** (M'56) as District Marketing Manager, Boston area, for Sylvania Electronic Systems, has recently been announced.

E. W. Harrington

With Sylvania since 1951, Mr. Harrington joined the company's Boston Engineering Laboratory which later became a unit of Sylvania Electronic Systems. He has served in a number of engineering supervisory positions.

Mr. Harrington received a Bachelor's degree in electrical engineering from Norwich University. He is a member of the Armed Forces Communications and Electronics Association.

❖

Dr. Nicholas E. Golovin (SM'61), formerly Technical Assistant to the Associate Administrator of the National Aeronautics and Space Administration and Director of the NASA-DOD Large Launch Vehicle Planning Group, has joined the technical staff of Dr. Jerome B. Wiesner, Special Assistant to the President for Science and Technology, Washington, D. C. In his new position, Dr. Golovin's principal area of interest will be space science and technology.

❖

(Continued on page 52A)

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SENSITIVE ELECTRONIC VTVM

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Price: $315

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GIVES YOU 1% ACCURACY OVER ENTIRE METER SCALE

1 mV-250V, 20 cps-20 kc

Ballantine's hand-calibrated logarithmic voltage scale makes it possible to read voltages to the same high accuracy at the bottom as at the top of the scale. You use the full 5 inches of mirror-backed scale. This instrument incorporates the best of the features developed in 25 years experience designing and building laboratory-quality vtvm's. Conservative operation of long life instrument tubes and high multiple path feedback over the frequency range result in a unit which is insensitive to tube deterioration or tube changes. There is less than ½% change in indicated voltage for a change in power supply voltage of 115 ±10%.

Every Model 300G is given a 50-hour "aging" at full power line voltage during a period of several days prior to its calibration. After calibration, each instrument is "aged" again for 3 to 4 hours and then cross-checked by a second operator at a second test console before final acceptance. This is **not** an occasional test but applies to **every** Ballantine instrument. Of course components such as indicating meters receive extensive testing prior to assembly into a vtvm.

You can be assured of more than 3000 hours use within specifications, without servicing or recalibration. The 300G is an excellent instrument for use as a reference standard in any electronics laboratory.

Frequency Range: 10 cps to 250 kc
Accuracy in % of reading anywhere on the scale: 1%, 1 mV to 250 V, 20 cps to 20 kc; 2%, 1 mV to 1000 V, 10 cps to 250 kc
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IRE People

(Continued from page 51A)

Dr. William L. Everitt (A'25–M'29–F'38), Dean of the College of Engineering, University of Illinois, has been elected a Director of Amphenol-Borg Electronics Corporation.

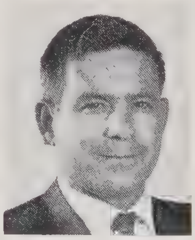
W. L. Everitt

Dr. Everitt is the author of many books and articles on engineering and is a member and former officer of many technical societies, including the American Association for the Advancement of Science, the American Institute of Electrical Engineers, the American Society for Engineering Education, and the National Society of Professional Engineers. He also has served on numerous committees and boards of Federal agencies and in 1946 received the War Department's Exceptionally Meritorious Civilian Award. At present he is a member of the Advisory Committee, Pacific Missile Range, U. S. Navy; and the sub-panel on Communications, Electronics, of the Army Scientific Advisory Panel.

A graduate of Cornell University with a B.S. degree in electrical engineering in 1922, Dr. Everitt received an M.S. degree from the University of Michigan in 1926, and a Ph.D. degree from Ohio State University in 1933. In addition to his work for the Government, he serves as Consulting Engineer for a number of industrial organizations.

❖

J. Paul Georgi (A'51–SM'54) has been named Technical Director of the Department of Defense's new Electromagnetic Compatibility Analysis Center, Annapolis, Md.


J. P. Georgi

Prior to receiving this assignment he has served over 18 years at Wright-Patterson Air Force Base in various military and civilian positions. During this time he was a member of numerous Air Force boards and committees in the electronic and weapon systems fields.

Mr. Georgi was graduated from the Ball State College of Indiana with a B.S. degree in 1949 and the Air Force Institute of Technology with a M.B.A., Weapon System Management, degree in 1960. He is a member of the Reserve Officer Association and the Air Force Association. In addition, Mr. Georgi is a past President of the Dayton Chapter Ball State Alumni Association, National Aeronautical Electronics Conference, and past Chairman of the Dayton Chapter of the Professional Group on Engineering Management.

❖

Kenneth G. McKay (M'47–SM'58) has been named an Executive Vice President of Bell Telephone Laboratories with responsibility for all systems engineering and related activities of the Laboratories.

K. G. McKay

A research physicist, Dr. McKay has been associated with electronic, semiconductor and solid-state research and development programs at Bell Laboratories since 1946.

Dr. McKay is a native of Montreal, Canada, and a graduate of McGill University, where he received the Bachelor of Science and Master of Science degrees in 1938 and 1939, respectively. He was awarded the Sc.D. degree by Massachusetts Institute of Technology in 1941 and worked with the National Research Council in Canada for the next five years.

Upon joining Bell Laboratories in 1946, he undertook fundamental research studies of the physics of solids, including studies of secondary electron emission and electron bombardment conductivity in insulators

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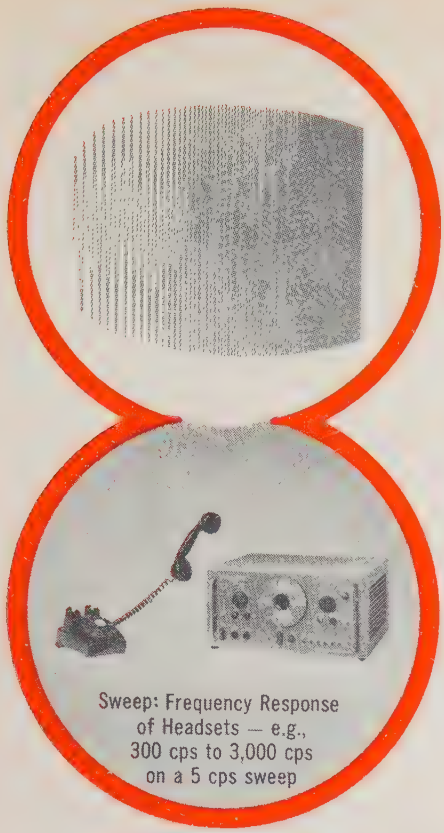
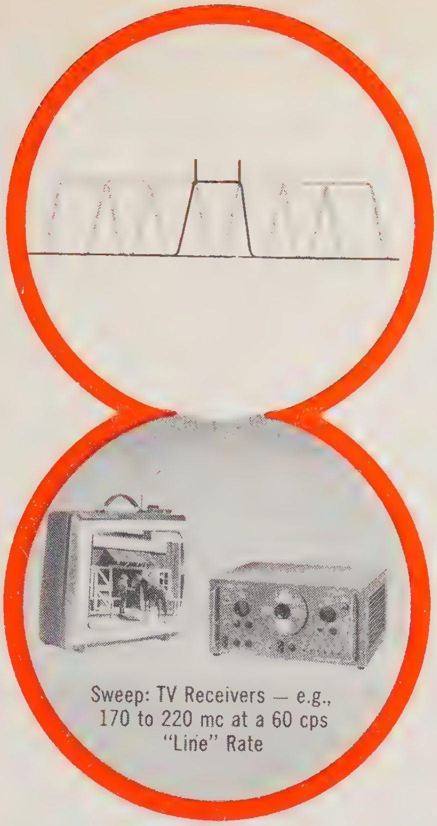
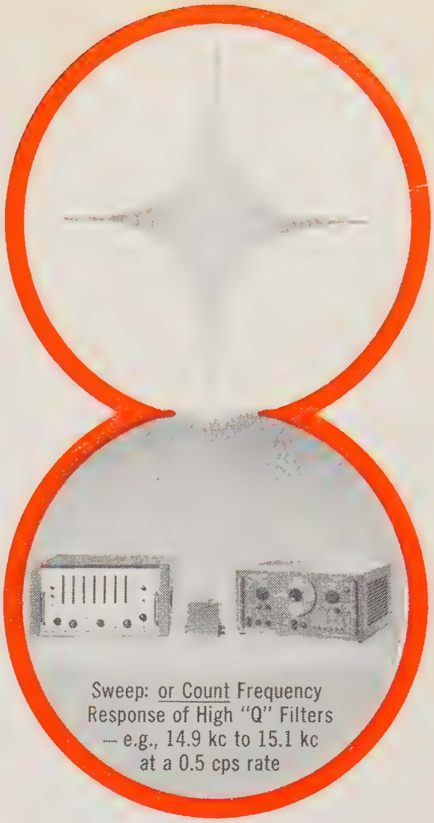


Sweep: Frequency Response of Headsets — e.g., 300 cps to 3,000 cps on a 5 cps sweep



Sweep: TV Receivers — e.g., 170 to 220 mc at a 60 cps "Line" Rate



Sweep: or Count Frequency Response of High "Q" Filters — e.g., 14.9 kc to 15.1 kc at a 0.5 cps rate

Complete VERSATILITY... *Audio, Video, VHF*

KAY *Ligna-Sweep* **SKV®**

All-Electronic

SWEEPING OSCILLATOR

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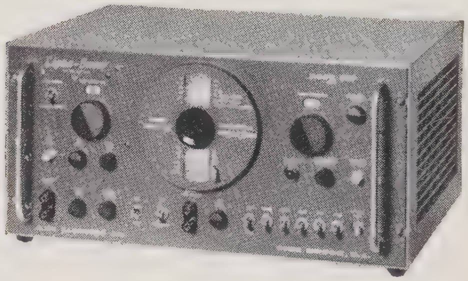

50 CPS TO 220 MC IN 12 BANDS • WIDE RANGE OF SWEEP WIDTHS
VARIABLE REP RATES • MANUAL AND AUTOMATIC OPERATION

- Single wide-sweep video displays from 10 mc down to 1 kc.
- Linear and logarithmic sweeps of 0.2 cps to 30 cps; or sweep locked to line frequency.
- Audio Sweep of 50 cps to 20,000 cps.
- 8 fixed, narrow-band video frequency sweeps for repetitive operations.
- Fundamental frequency 10 mc to 220 mc (widths to 30 mc plus).
- High-level output of 1 V rms into 70 ohms. AGC'd to ± 0.5 db over widest sweep.
- Manually-operated control for varying oscillator frequency.
- Fixed pulse-type markers or variable marker provision.

Price: $1295.00 F.O.B., Factory ($1425.00 F.A.S., New York).

The wide frequency range, extensive choice of sweep widths and repetition rates make the Kay *Ligna-Sweep* SKV a most useful sweeping oscillator.

For high frequency work, the unit provides 9 sweep bands, operating at fundamental frequencies for wide, stable sweeps from 10 to 220 mc. At the low end of the spectrum, an audio frequency sweep from 50 to 20,000 cps is provided. High order stability permits frequency sweeps to as low as 50 cps.

For checking high-Q circuits and low-frequency response characteristics, either log or linear sweeps at variable rep rates down to 0.2 cps are available. This wide choice of sweep rates (continuous to 30 cycles, and fixed line lock) makes it easy to select that highest *rep rate* which gives both an *accurate response* display and easiest, brightest viewing on the scope screen. With the manual frequency control, the trace on the scope screen may be held and examined in detail, (counted precisely, measured on a VTVM) at any frequency point on the scope display.

Check Video Bandpass — e.g., 1 kc to 10 mc at 1 cps rate

Check Radar IF's — e.g., 25 to 35 mc at 30 cps

Check Audio Bandpass — e.g., 50 cps to 20 kc at 1 cps Log Sweep

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Dynacor Square-Loop Tape Cores are manufactured with the high permeability alloys—Grain-Oriented 50-50 Nickel Iron, 4-79 Molybdenum Permalloy, and Grain-Oriented 3% Silicon Iron . . . with fully guaranteed uniformity . . . under rigid standards of control and inspection.

Look to Dynacor for reliable production and swift delivery of your tape core requirements. For your convenience a full line of standard units are stocked for immediate off-the-shelf delivery—Send for bulletins DN 2000, DN 2001, DN 2002.

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IRE People

(Continued from page 52A)

and semiconductors. Later his work related to the electrical and optical characteristics of electrical breakdown in germanium and silicon.

He was named Director of Development of solid-state devices in 1957, Director of Development of components and solid-state devices in 1958, and elected a Vice President in 1959.

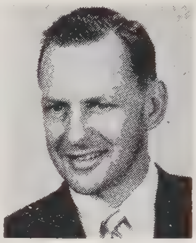
Dr. McKay has been granted nine patents for his electronic inventions, and has written extensively on solid-state physics for scientific publications.

He is a Fellow of the American Physical Society and served on the Board of Editors of *The Physical Review* from 1955 to 1957. He is a member of the Research Society of America.

❖

Dean C. Bradford (A'45–M'55) previously Manager of the ITT special-purpose tube plant at Roanoke, Va., was promoted to head the new tube department, of the ITT Components Division of International Telephone and Telegraph Corporation, N. J.

Mr. Bradford is a graduate of Pennsylvania State University. He is a member of the IRE Professional Group on Electron Devices, and the American Management Association. He has had 15 year's service with ITT.



D. C. Bradford

❖

Dr. Frederick J. Milford (M'58) has been appointed Assistant Director of Technical Development at Battelle Memorial Institute.

In his new post, Dr. Milford will guide the expanding program of fundamental scientific studies being supported directly by the institute. He will also continue his own research in theoretical physics in the Mathematics and Theoretical Physics Division of the Physics Department.

F. J. Milford

Dr. Milford holds a Bachelor of Science degree in physics from Case Institute of Technology and a Doctorate in Physics from Massachusetts Institute of Technology. Prior to joining the physics staff of the Columbus, Ohio, research center in 1959, he had served as Assistant Professor of Physics at Case Institute of Technology.

His studies include work in the theory of structure of heavy nuclei, relativistic wave equations, cosmic ray theory, and quantum theory of solids. He is author with John R. Reitz of the book "Foundations of Electromagnetic Theory." At Battelle he has done work on the Knight shift of the alkali metals and beryllium, the theory of spin waves, and is currently investigating the low-temperature magnetic susceptibility of ruby.

Dr. Milford is a member of the American Physical Society and Sigma Xi.

❖

Albert E. Doles (S'56–M'56) has been elected a Vice President and member of the Board of Directors of Eberline Instrument Corporation.

Mr. Doles, who was Technical Director, will have primary responspibility for all technical phases of the company's nuclear instrumentation engineering and production, radiochemistry and radiological health services.

A. E. Doles

In March he returned to Santa Fe after completing an assignment for Eberline as the nuclear instrumentation member of the start-up team at the Enrico Fermi Atomic Power Plant, Newport, Mich. He joined Eberline in 1956 following service as a U. S. Navy Aviation Electronics Officer. Prior to his assignment at the Enrico Fermi reactor project, he was Eberline's Assistant Chief Engineer.

A graduate of Kansas State University with high honors in electrical engineering, Mr Doles has taken graduate studies at the University of New Mexico in nuclear and reactor engineering.

Mr. Doles is a member of Kappa Mu Epsilon, Phi Kappa Phi, and Eta Kappa Nu.

❖

Dr. Paul I. Richards (A'45) has been appointed to the position of Corporate Fellow of Technical Operations, Inc.

Dr. Richards joined Technical Operations in May of 1954. In the ensuing eight years, he has contributed significantly to the theories on the effects of nuclear weapon phenomenology under contracts between Technical Operations and various branches of the armed forces. Most recently, he has conducted blast-wave calculations for Technical Operations under contract with the Army Ordnance Corps.

P. I. Richards

A graduate of Harvard University with a Ph.D. degree in physics, Dr. Richards is a member of the American Physical Society.

❖

(Continued on page 56A)

Wire-lead printed circuit Mini-Trimmer; also available in tab-lead panel mount, and sealed types.

High Q—500 at 50 Mc*

and 5 other reasons Corning Mini-Trimmers give you better circuits

No tuning breakage—unique *direct traverse* design moves tuning core without rotation.

Complete linear tuning—DT motion and fine-thread screw give smooth precision; capacitance change per turn of 0.4 to 0.6 *pf*.

Shock and heat resistant–the ruggedly simple units of glass, fired-in metallizing, and special hardware can take tremendous abuse. TC is ±50 to ±100 ppm/°C.

Guaranteed: no capacitance reversals–we guarantee this within the range of the unit.

Lower contact resistance–all hardware is silver plated; this boosts circuit Q, too.

You get all this and high Q, too, in panel mount, wire- or tab-lead printed circuit, and our *new* hermetically sealed Mini-Trimmers. Four sizes in each type to give you *pf* min.-max. ranges of 1-4.5, 1-8.5, 1-12, and 1-18 at 1000 DC volts.

Dimensions: panel mount, $\frac{27}{64}''$ to $1\frac{3}{32}''$ behind panel, $\frac{1}{4}''$ front of panel; printed circuit, $\frac{27}{64}''$ to $1\frac{3}{32}''$ overall.

You can get *fast* delivery on Corning Mini-Trimmers from your nearest Corning distributor. You can get more information and data sheets fast from us–Corning Glass Works, 3902 Electronics Drive, Raleigh, N. C.

**Guaranteed*—unusual footnote, eh? The glass we put into these trimmers has a loss factor of only 0.50. Nobody else uses it. We make it ourselves, control it all the way.

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IRE People

(Continued from page 54A)

The appointment of **Julius Leonhard** (S'50–A'52–M'57) as Consultant to the Director of Research and Development at Page Communications Engineers, Inc., was announced recently.

J. Leonhard

Mr. Leonhard has more than 20 years' experience in radio engineering. He was a pioneer worker in the development of troposcatter communications and has become a specialist in natural and artificial interference and anti-jamming techniques.

Before joining Page, he was a staff member of the Communications Department at ITEK Laboratories, Lexington, Mass. Earlier he was a staff member with Hermes Electronics Co., where he worked on system design and equipment specifications for troposcatter links of the Hycon-Page Libya telephone network.

During the period May 1957 to June 1961 he was Technical Director and then Project Manager of the Hycon Eastern effort on the SHAPE project ACE HIGH, a 13-nation troposcatter communications network.

Mr. Leonhard is a graduate of the Massachusetts Institute of Technology with a S.B. degree. He is a Member of Eta Kappa Nu, Tau Beta Pi, and Society of Sigma Xi.

He has published professional papers in the Proceedings of the IRE and IRE Transactions on antennas and Propagation.

⁂

Dr. Oliver R. Price (SM'59) has been named Chief Engineer of Micro-Radionics, Inc., Van Nuys, Calif.

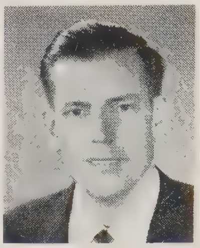
O. R. Price

Dr. Price will bring a background of microwave knowledge and experience to his new position. For a number of years he was Project Engineer, heading the Advanced Studies Section, of Hughes Aircraft Research and Development Laboratories. Earlier he was Research Physicist in the High Energy Physics Laboratory of the University of California, Los Angeles. He also lectured at West Coast University for two years and was a member of the technical staff of Hughes Aircraft Microwave Laboratory. Dr. Price has published a number of technical papers on-various microwave design techniques.

He is a graduate of California Institute of Technology and holds his Ph.D. degree in physics from the University of California. He is a senior member of the American Physical Society, Sigma Xi, RESA, AAAS, and Sigma Pi Sigma.

⁂

Nathan W. Aram (S'39–A'41–M'45) has been appointed Vice President-Chief Engineer by the board of directors of Zenith Radio Corporation.



N. W. Aram

Mr. Aram has been Assistant Vice President and Chief Engineer since August, 1958. He joined the company's engineering staff in June 1939, working in television and FM transmitter development and later on radar and other military electronic projects. In 1946 he became Electrical Engineering Supervisor of TV receiver design. More recently, he headed the development of the new Stereophonic FM broadcast service as introduced commercially in June of 1961.

He attended Augustana College in Rock Island, Illinois, from 1935 to 1937, where he also was a radio operator for station WHBF. He completed his undergraduate study at Purdue University, receiving the Bachelor of Science degree in electrical engineering, and was elected to Eta Kappa Nu and Sigma Xi, honorary fraternities. He was also an operator of the University's experimental television station. After joining Zenith, he attended graduate school at Northwestern University.

Aram is a member of the Chicago Radio Engineer's Club, and is a registered professional engineer.

⁂

Willard Fenn (S'38–A'43–SM'50) former Section Secretary, WESCON Technical Program Chairman, Development Committee Chairman, and holder of numerous other Section IRE posts, has opened his own consulting firm in Los Angeles, Calif.

W. Fenn

Mr. Fenn was with the M.I.T. Radiation Laboratory and later helped found Polytechnic Research and Development Co., and FXR. For ten years he was with Hughes Aircraft. He has served on EIA technical committees.

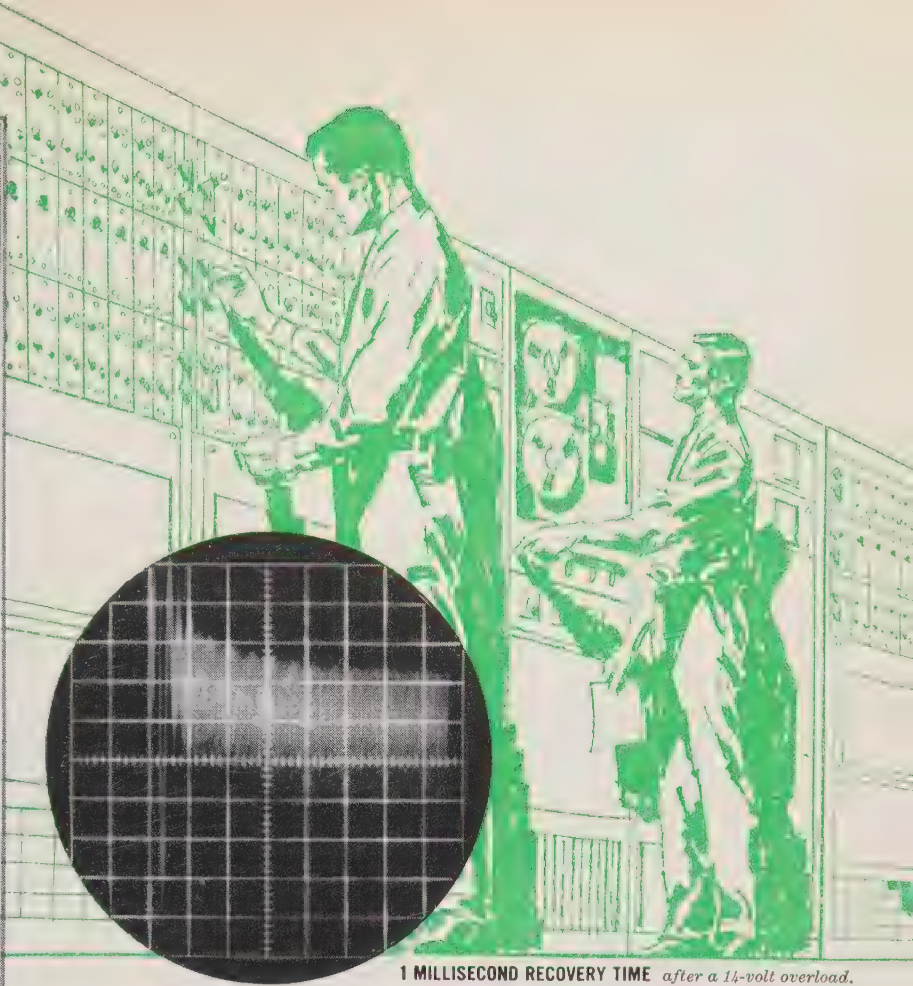
In his twenty years in microwaves, Mr. Fenn invented the first directional coupler and the temperature compensated thermistor power bridge. As a consultant he will work on design and marketing of precision microwave measurement equipment and instrumentation.

⁂

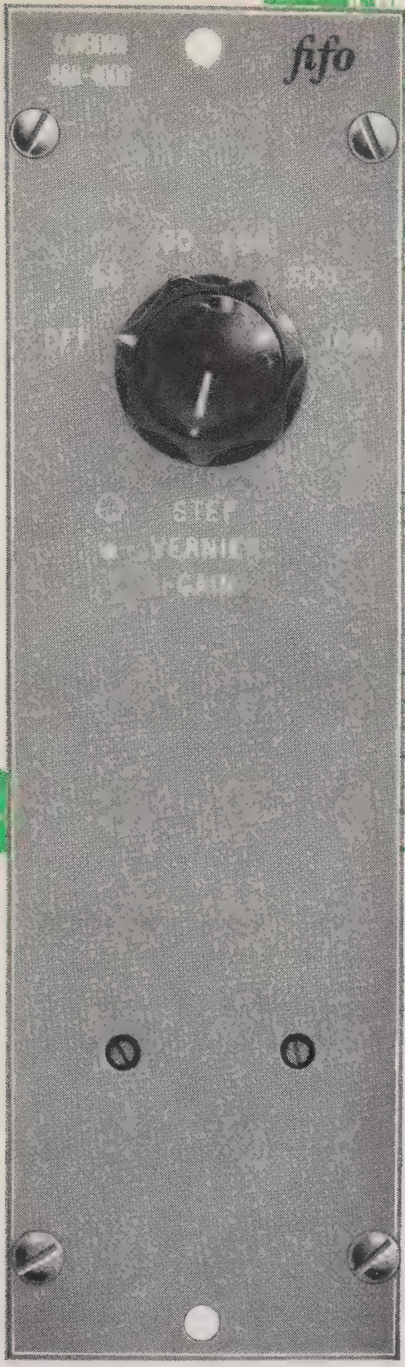
(Continued on page 102A)

Primarily for Frequency Standard Use Under Rigorous Environmental Conditions.
5 MEGACYCLES 5th OVERTONE
JK PRODUCTS

Aging: 1 x 10^{-9}/day. **Frequency Change:** Less than 1 x 10^{-8} under vibration of 10 to 200 cps at 10 G, and under 100 G shock when tested per MIL-STD 202A Method 202A. **Frequency Range:** From 4.966 mc to 6.133 mc. Write for literature to James Knights Company, Sandwich, Illinois.



1 MILLISECOND RECOVERY TIME *after a 14-volt overload. Time base, 1/2 ms/div; amplitude, 2% of full scale. A small AC signal was mixed with the overload to increase visibility of recovery trace.*



Sanborn® FIFO—fully transistorized, shown actual size

NEW 0-10 KC Floating Input-Floating Output DC AMPLIFIER

The new FIFO (floating input—floating output) is a fully transistorized amplifier designed especially for obtaining data from wide bandwidth transducers. A single FIFO used with an input scanner can amplify data from many transducers, or the outputs of any number of FIFO amplifiers may be sampled.

Model 860-4000, with gain of 1000, is particularly useful for extracting low level signals from a high noise level. Model 860-4000P (with grounded output isolated from input) can deliver ±5 volts at ±100 ma and is suitable for driving high frequency galvanometers. Both FIFO models have a high common mode rejection ratio and, as illustrated by the 'scope photo, exceptional overload recovery capability.

The FIFO amplifier is available in a portable case with individual power supply. Two channels with individual power supplies are available on a 3½″ x 19″ panel for rack mounting, or you can mount eight amplifiers in 7″ x 19″ with a Sanborn Model 868-500F 8-channel power supply.

Contact the Sanborn Industrial Sales-Engineering representative nearest you or write the main office in Waltham for complete information and engineering assistance.

INDUSTRIAL DIVISION
SANBORN COMPANY
175 Wyman Street, Waltham 54, Massachusetts
A SUBSIDIARY OF HEWLETT-PACKARD COMPANY

SPECIFICATIONS: MODEL 860-4000 FIFO AMPLIFIER

Isolated, floating, guarded input — 100 meg. impedance min. at DC

Isolated, floating output — impedance less than 35 ohms

Bandwidth DC to 3 db down at 10 KC

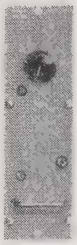
Max. Gain of 1000—10 mv in gives ±10 volts out across 1000 ohms (floating). Optional Model 860-4000P with power output isolated from input can deliver ±5 volts at ±100 ma at ground potential

Linearity ±0.1% of 10-volt floating output at DC

High Common Mode Rejection—160 db at DC, 120 db at 60 cps, 100 db at 400 cps, with 1000 ohms unbalance at source

Drift 2 uv, Noise 7 uv RMS

Specifications subject to change without notice.



For DC to 100 cps bandwidth

DATA PREAMPLIFIER 860-1500S

Has floating, guarded input and floating output; delivers ±5 volts across 2000 ohms; linearity ±0.05% of full scale (5 volts); bandwidth DC to 3 db down at 100 cps; rejection ratio 10^6:1 with 5000-ohm source unbalance at 60 cycles. Either fixed gain between 10 and 2000, or with attenuator to provide any selected gain within this range. Amplifier has less than 2 uv drift and less than 3 uv peak-to-peak noise.

New
Ferrite Materials
and configurations
Offer broad New range
of inductive component
Design Opportunities

Greater advancement in the capabilities of ferrites have occurred during the past 15 months than at any time since the semiconductor material's discovery. During this period a whole new generation of materials has been introduced by Ferroxcube. All have been developed specifically for critical telecommunications, military and other industrial applications. Nearly every important characteristic has been improved by at least 100%. For example—available initial permeabilities have jumped to 4300. Obtainable "Q" values have been doubled or tripled. Temperature stability has been improved by an even greater factor.

Many new configurations have been designed and are now offered as standard parts. Pot core dimensions have been optimized for maximum "Q's." "E" cores with dimensions the same as standard laminations for simple interchangeability offer large cost savings. Broader lines of toroids with more closely controlled characteristics all offer new design opportunities.

Ferroxcube is uniquely equipped to offer the full benefit of these new developments. Ferroxcube produces ferrites only for the demanding professional application. Ferroxcube can control more of the material's characteristics simultaneously because its processing is more closely controlled. Batch kiln firing and segregated powder preparation are the biggest factors. Only batch kiln firing allows accurate control of both temperature and atmosphere during processing. The result is control of all critical characteristics. In evaluating ferrite devices, consideration must be given to disaccommodation, temperature stability, permeability as well as "Q." The higher the "Q" the more important these stability factors become.

Only Ferroxcube cores allow you to take full advantage of these new advances because only Ferroxcube's facilities allow full control of stability and repeatability over a period of time.

Evaluate these advances. See what they can do to open up new products for you or to improve performance of your present line.

Ferroxcube's application staff will be glad to help. Why not start now by requesting our new Inductive Core Literature.

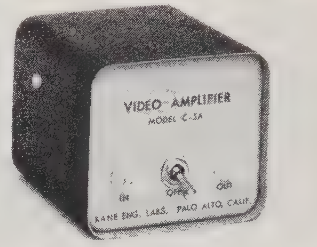
FERRITES
FIRST IN
FERROXCUBE
CORPORATION OF AMERICA
SAUGERTIES, NEW YORK

NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

Powered Amplifiers

Battery-powered transistor amplifiers have been introduced by **Kane Engineer-Laboratories,** 845 Commercial St., Palo Alto, Calif. They are compact moderately priced instruments for general laboratory use, and offer stable, hum-free operation and eliminate power-line noise interferences and ground-loop problems.



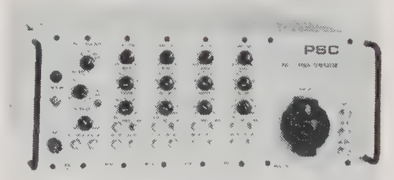
Four models, audio and video with high or low input impedance, are priced from $75.00 to $95.00. Available gain figures are 30, 35 and 40 decibels from 6 cps to 100 kc (audio models) and from 6 cps to 2 mc (video models), with good noise performance.

Primary application in general laboratory use is for improvement of sensitivity of oscilloscopes, recorders, and so forth. Circuits employed are bias stable and provide flat response over stated frequency range.

Additional information is available from the firm.

Pulse Train Generator

A pulse train generator of unusual capabilities was introduced by **Physical Science Corp.,** 176 Linwood Ave., Fairfield, Conn.



Generating a 4-pulse train with a rise time and fall time of 1.5 nanoseconds, the Model 102 permits simulation of pulse rates up to 300 million per second with pulse amplitudes continuously variable and by calibrated 1 db steps, up to 25 volts maximum, and with pulse widths from 0 to 50 nanoseconds continuously variable by panel control. Pulse position is continuously variable from 0 to 300 nanoseconds and output pulses are available in train at a common output or at individual outputs. Polarity, negative or positive, is individually set for pulses. Pulses in a train are all negative or all positive.

The Model 102 is designed to permit the combining of pulses in any desired train pattern:

(1) In close sequence, with 3 ns separation, peak-to-peak, simulating 300 megapulses/second, with amplitude up to 25 volts.

(2) Superimposed to form a staircase of any desired size and shape.

(3) In sequence, as required, to measure system recovery thresholds as a function of time lag, pulse width, and pulse amplitude.

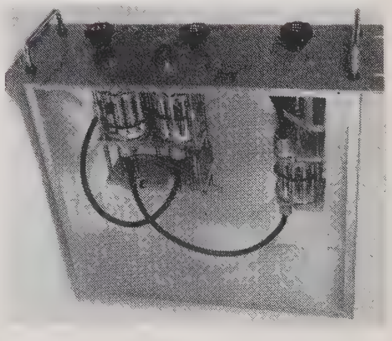
(4) In sequence, as required to measure switching response of components and circuits.

(5) Superimposed as a single pulse of 1.5 ns rise and fall times, delivering 2 amperes into 50 ohms.

The train repetition rate is continuously variable from 1 pps to 10K pps. Triggered and one shot operation is also available. The Model 102 is priced at $2850, with delivery 60 to 90 days from receipt of order.

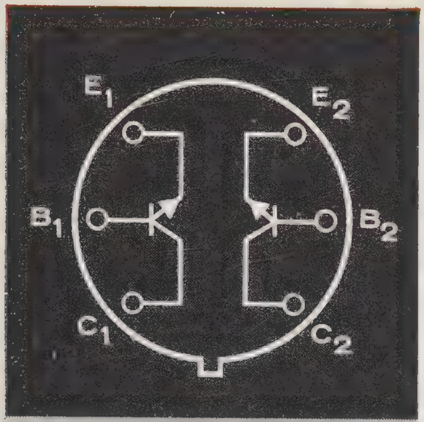
RF Step Attenuators

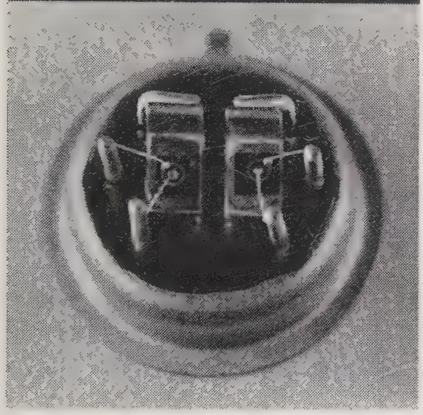
The new RF step attenuators manufactured by **Stoddart Aircraft Radio Co., Inc.,** 6644 Santa Monica Blvd., Hollywood 38, Calif., are a further development of the original models using the "Pull-Turn-Push" turret control. They are designed for use with standard 50-ohm coaxial cable circuits, and are available in either two or three turret models. These attenuators have exceptional stability, and are highly accurate from dc to 3 gigacycles with an exceptionally low phase shift characteristic at IF frequencies up to 160 mc. The phase shift is less than 0.1 degree at 30 mc referred to straight thru (0 db) position.



(Continued on page 60A)

DUAL TRANSISTORS





IN A SINGLE TO-5 PACKAGE

- All leads isolated
- Improved thermal tracking
- Less board space
- A wide range of Fairchild Silicon Planar or Silicon Planar Epitaxial transistors
- Fairchild Planar reliability

FAIRCHILD TRANSISTORS AVAILABLE IN DUALS

Similar Types	Dual	Similar Types	Dual	Similar Types	Dual
2N708	SP8300	2N916	SP8306	2N2297	SP8312
2N709	SP8301	2N995	SP8307	2N2368	SP8313
2N910	SP8302	2N1132	SP8308	2N2369	SP8314
2N911	SP8303	2N1613	SP8309		
2N914	SP8304	2N1711	SP8310		
2N915	SP8305	2N1893	SP8311		

MATCHED AMPLIFIER TYPES AVAILABLE

2N2060†	2N2223†	2N2223A†	SP8305A (2N915)*	SP8306A (2N916)*

*Matched Beta within 10% at $I_c = 1$ mA, and $V_{CE} = 5$ V; $V_{BE1} - V_{BE2}$ (absolute values) ≤ 0.005 V.

†See data sheets for matching specifications.

For complete information, check your Fairchild Sales Representative.

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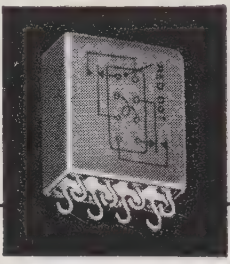
Crystal Can Relays
offer *PROVED* reliability
plus design flexibility

■ CLARE Crystal Can Relays, available with either latching or non-latching circuitry, offer the designer a constantly higher norm of *proved* reliability.

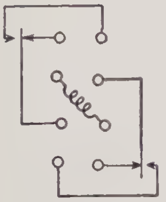
The CLARE Quality Assurance Program tests these relays to provide check of a broad cross section of the materials, the processes and the individual skills which contribute to their fabrication. Sample lots are selected, tested in general accordance with MIL-R-5757D (par.4.6.1.4., Group B), then tested to failure, to discover the cause of final breakdown...and take steps toward increasing reliability.

Information on how these tests are performed is available on request.

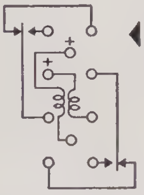
Type F and Type LF ▶
(both one-coil and two-coil) relays in one-sized enclosure.



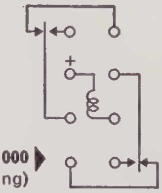
LATCHING OR NON-LATCHING CIRCUITS



◀ **Type F**
(non-latching)



◀ **Type LF2000** (two-coil latching) Additional coil termination configurations on request.



Type LF-1000 ▶
(one-coil latching)

For complete information send for Catalog 203 and Bulletin CPC-12. Address: C. P. Clare & Co., 3101 Pratt Blvd., Chicago 45, Illinois. Cable Address: CLARELAY. In Canada: C. P. Clare Canada, Ltd., 840 Caledonia Road, Toronto 19, Ontario. In Europe: Europelec, les Clayes-sous-Bois (S.-et-O.), France.

C. P. CLARE & CO.
Relays and related control components

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 58A)

The two-turret model ($920.00) provides attenuation in 1.0 db steps from 0 up to 70 db. The three-turret model provides attenuation from 0 to 71 db in steps of 0.1 db. Other attenuation steps can be provided to suit customers' needs. The turret switches are of heavy-duty type, and are so well designed that they will give many years of trouble-free operation. The three-turret model ($1,395.00) is designed for standard rack mounting, and the two-turret model can be removed as a unit from its case and mounted on any other panel.

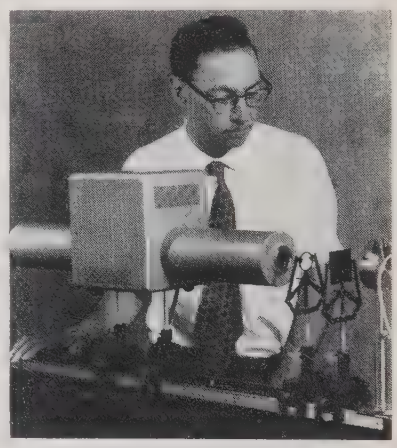
Both units are compact, precision built and ruggedly constructed. The resistive networks are composed of permanently stable elements and all switch contacts are gold plated. The attenuators have type N, female connectors and will handle one watt maximum average power. VSWR is less than 1.5 over-all. Insertion loss tolerances are from ±0.1 db for pads with values less than 1.4 db, up to ±1.0 db for 60 db pads (dependent upon frequency).

Continuous Wave Gas Phase Laser

The first low cost, commercially available continuous wave gas phase laser was announced today by the **Perkin-Elmer Corp.,** Norwalk, Conn., and **Spectra-Physics, Inc.,** Mountain View, Calif. The system, developed jointly by the two companies, will be marketed by Perkin-Elmer's Optical Maser Department. It will sell for approximately $7500.

The importance of the new general purpose gas laser, which uses a mixture of helium and neon gases as the active medium, is that it produces a *continuous*—rather than a pulsed—beam of highly directional coherent light. A general characteristic of helium-neon gas phase lasers is that they produce the most monochromatic (ultra-pure color) source of light known.

The combination of these characteristics means that the low cost gas laser can be used for communications experiments, some of which are not possible with pulsed lasers; as a valuable tool in long distance interferometry, which is used for accurate measurement of lengths and velocities; for spectral studies; and as a light source for testing advanced optical lenses and systems, as well as for general experimental work with coherent light.



The helium-neon gas phase laser was invented by Ali Javan and further developed at Bell Telephone Laboratories by Javan, W. R. Bennett, Jr., D. R. Herriott and others. The Perkin-Elmer/Spectra-Physics laser is based on this invention.

It is a compact, lightweight (13 pounds) unit, and can be mounted on standard optical benches.

It produces a continuous monochromatic beam of coherent light of about 1 milliwatt at an output wavelength of 11,530 angstroms in the near infrared region of the spectrum. The beam is highly directional with a spread of less than one minute of arc when focused to a parallel beam.

The laser's resonator is a two-foot-long fused silica tube with internal confocal reflectors which have a multilayer dielectric coating. The tube is contained in a 3.5 inch diameter protective housing. The fused silica construction provides thermal stability.

(Continued on page 62A)

T. B. Curtz
Numerical Analysis, Computation

R. V. Attarian
Electronics Systems

L. J. Cutrona
Radar, Communications, Information Theory

J. W. Crispin, Jr.
Radar Cross Sections

R. R. Graham
Radar, Antennas, Microwave Networks

D. M. Grimes
Ferrites, Electromagnetic Field Theory

R. J. Hach
Ferrite Materials

A. L. Ingalls
Optics, Image Processing

I. W. Kay
Mathematics, Wave Propagation and Diffraction

F. T. Johnson
Physics—System Analysis

R. E. Machol
System Engineering

A. L. Maffett
Non-uniform Arrays, Scattering

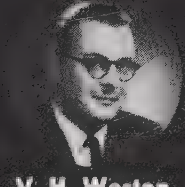
D. V. Ragone
Materials, Structures, Properties

P. Swerling
Information, Detection Theory

D. M. Raybin
Electromagnetic Theory, Plasma Physics

K. M. Siegel
Radar Cross Sections, Plasma Physics

R. K. Ritt
Diffraction, Differential Equations



V. H. Weston
Electromagnetic Wave Theory

W. E. Vivian
Radar, Radiometer Techniques

L. Weinberg
Network Analysis and Synthesis

A. W. Wren, Jr.
Antennas and Propagation

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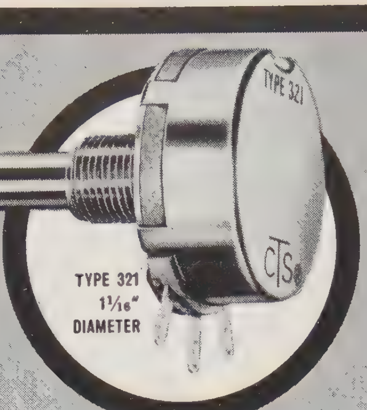

3-WATT
Military Grade
VARIABLE RESISTOR
AT 2-WATT
INDUSTRIAL PRICE

The excellent heat sink of unique carbon-ceramic element offers stability under high wattage and temperatures—plus the performance and reliability of a military grade variable resistor at a commercial price.

CTS Type 321 has the stability of MIL-R-94B. Write for Catalog.

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BERNE, INDIANA
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NEWS New Products

(Continued from page 60A)

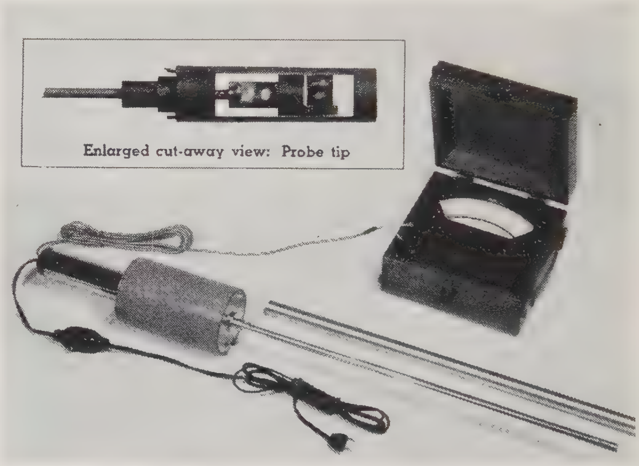
The use of confocal mirrors eliminates the need for any adjustment of the tube's end reflectors.

The excitation unit, integrally mounted in the center of the plasma tube, is a 40 watt, 40.68 megacycle radio frequency oscillator. A remote supply provides the necessary dc power. The advantage of an integrally mounted RF unit is that it eliminates the need for RF matching adjustments.

Gas phase lasers operate on the same general principle as do solid state lasers. The major difference is that the active medium is a helium-neon gas mixture, rather than a crystal material such as ruby or calcium tungstate.

Three Dimensional Gaussmeter

In addition to the usual rotating coil for transverse fields, this new gaussmeter designed by **Rawson Electrical Instrument Co.**, 118 Potter St., Cambridge 42, Mass., has a second coil arranged to measure the field along the axis. The field can be measured in three dimensions by combining the results of measurements with the two coils. It is possible to make convenient and highly accurate measurements of the magnetic fields of solenoids, focussing coils and magnets for ion or electron beams.

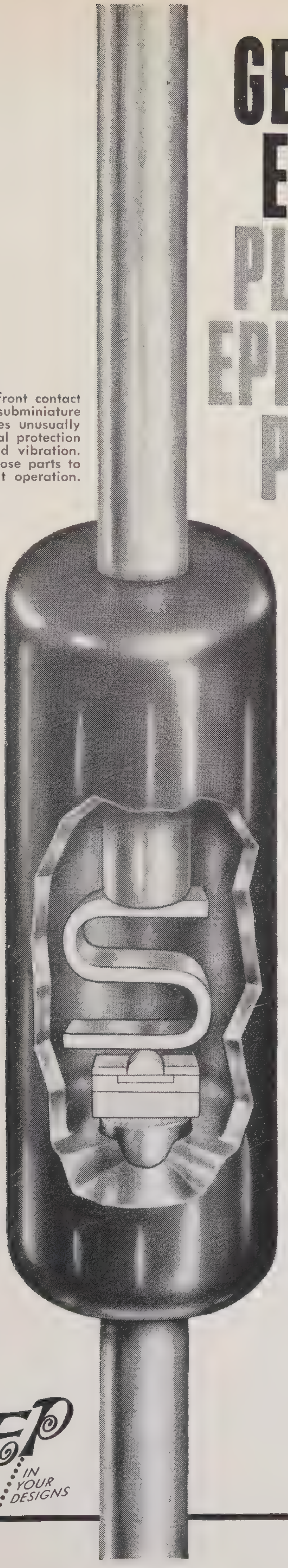


The new Rawson-Lush rotating coil gaussmeter features a gear-driven coil rotating at right angles to the drive shaft so that it can cut the lines along the axis. Although the moving parts are almost microscopic in size, an operating life of at least 1,000 hours has been achieved by proper choice of materials and a number of design innovations. The coil is driven by a modified bevel gear arrangement with a nylon driving gear. Spring-loaded silver slip rings make a long-lasting electrical connection to the rotating coil. The coils are molded in epoxy cylinders. The entire assembly of coils, gears, slip rings, and bearings runs in oil to minimize wear.

For years the standard Rawson-Lush rotating coil gaussmeter has been extensively used to measure fields across the axis. This type of gaussmeter is perfectly linear, requires no amplification or complicated circuitry, does not require a uniform field and is relatively free from temperature effects. However, it has not been possible to measure along the axis, the direction most needed for measurements in solenoids. Solenoids are coming into wide use for travelling wave tubes and other electron and ion beam devices, also in very high field physics research. The new dual-coil unit is expected to find wide use in these application areas.

The Type 729 gaussmeter specifications are: Diameter of probe, $\frac{7}{16}''$; length of probe, approx. 20″ (longer or shorter lengths are also available); diameter of rotating coils, approx. $\frac{3}{16}''$; ranges, 0.4/1.2/4/12/40/120 kilogausses, full scale; scale length of meter, 5 inches; guaranteed accuracy, 1% of full scale. Price, $750; availability, approximately 90 days.

(Continued on page 128A)



Fused hemisphere front contact in the glass subminiature package provides unusually good mechanical protection against shock and vibration. There are no loose parts to cause intermittent operation.

GENERAL ELECTRIC PLANAR EPITAXIAL PASSIVATED DIODES

FEATURE CONTROLLED CONDUCTANCE

General Electric PEP silicon diodes bring you a unique design combination that allows ultra-fast switching speed combined with extremely tightly controlled conductance over a wide current range.

Gaseous *planar* diffused junction means high breakdown voltage with low capacitance.

Thin *epitaxial* layer on low resistivity substrate gives negligible body drop and increased uniformity from diode to diode.

Surface *passivation* is applied before the junction is formed for maximum protection against contamination.

FORWARD VOLTAGE CHARACTERISTICS

1N3605 1N3606	1N3608 1N3609	
I_F (ma)	V_F (millivolts)	
	Min.	Max.
0.1	485	555
0.250	525	595
1.0	580	680
2.0	625	725
10.0	710	840
20.0	750	900

	1N3605 1N3608	1N3606 1N3609
Breakdown Voltage (I_R=5 µamps)	40 V min.	75 V min.
Leakage Current (25°C)	50 ηamps max. @ V_R=30V	50 ηamps max. @ V_R=50V
Leakage Current (150°C)	50 µamps max. @ V_R=30V	50 µamps max. @ V_R=50V

1N3605 AND 1N3606 ARE IN THE GLASS SUBMINIATURE PACKAGE ILLUSTRATED. 1N3608 AND 1N3609 ARE IN A MICROMINIATURE PACKAGE.

If your application does not require controlled conductance and exceptionally tight specifications, G-E also has available 1N3063. For complete details, call your Semiconductor District Sales Manager. Or write Semiconductor Products Department, Section 23G118, General Electric Company, Electronics Park, Syracuse, N.Y. In Canada: Canadian General Electric, 189 Dufferin St., Toronto, Ont. Export: International General Electric, 159 Madison Ave., New York, N.Y.

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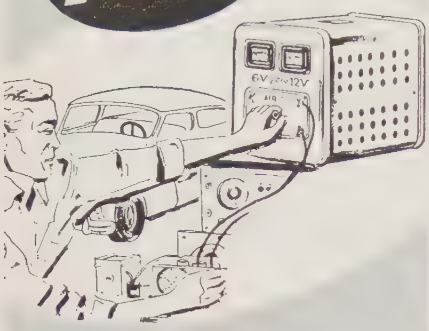
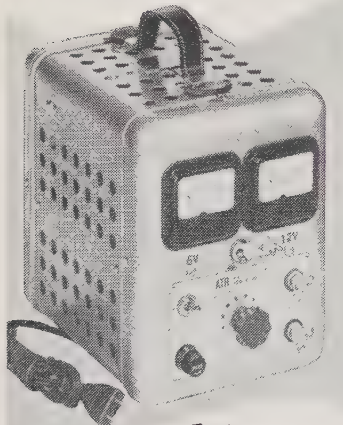
PUT PEP IN YOUR DESIGNS

GENERAL ELECTRIC

ATR



"A" BATTERY ELIMINATORS



For Demonstrating and Testing Auto Radios

TRANSISTOR OR VIBRATOR OPERATED

6 Volt or 12 Volt!

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			AMPERES Cont.	Int.		
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Professional Group Meetings

Aerospace and Navigational Electronics

Baltimore—April 17

"Automatic Landings," P. A. Noxon, Bendix Corp., Eclipse Pioneer Div.

Baltimore—February 20

"Phased Arrays," Dr. M. Skolnik, Electronic Communications, Inc., Timonium, Md.

Boston—April 26

"Lasers—A New Sensing Element for Navigation and Surveillance," A. Soltes, Raytheon, Wayland.

Boston—March 15

"Transit Revisited," Dr. G. C. Weiffenbach, APL John Hopkins University, Silver Springs, Md.

New York—February 8

"Flarescan," H. Hechtman, Airborne Instrument Lab., Deer Park, L. I.

"Advanced Sensors for Inertial Guidance and Navigation for Aerospace Vehicles," Dr. B. Lichtenstein, Kearfott, Little Falls, N. J.

New York—November 9

"Supersonic Transport Navigation Systems," A. Paradiso, Douglas Aircraft Corp., Long Beach, Calif.

Oklahoma City—April 29

"Collins Airborne Antennas," M. V. Anderson, Collins Radio Co., Richardson, Tex.

Antennas and Propagation

Boston—April 25

"A New Approach to the Theory of Arrays," Prof. R. W. P. King, Harvard University.

"Cross-Coupling in Multiple Beam Antennas," Dr. S. Stein, Sylvania, Waltham, Mass.

Boston—March 21

"Plasma Covered Antennas," G. Meltz, AFC RL, Bedford, Mass.

"Phase Steering by Digitally-Controlled Time Delays," J. Duffy, Sylvania, Waltham, Mass.

Chicago—April 13

"VHF and UHF Antennas," M. W. Scheldorf, Armour Research Foundation, Chicago.

Washington, D. C.—February 20

"Radio Astronomy," C. H. Mayer, Naval Res. Lab., Washington, D. C.

Antennas and Propagation and Microwave Theory and Techniques

Baltimore—April 16

"Microwave Radiation Hazards," W. W. Mumford, Bell Telephone Labs.

Columbus—April 5

"Collision-Free Current Sheets in Plasma," Dr. O. K. Mawardi, Case Institute of Technology, Cleveland.

San Diego—March 13

"A Unique V.L.F. Sounder for Studies of the Lower Ionosphere," M. Paulson, U. S. Navy Electronics Lab., San Diego.

Syracuse—May 1

"MOSAR," P. Howello, General Electric Co., Syracuse, N. Y.

Audio

Boston—March 22

"Machine Generation and Recognition of Speech," Prof. K. N. Stevens, M. I. T.

Cleveland—January 25

"Acoustic Treatment of the Cleveland Auditorium," Dr. J. L. Hunter, John Carroll University, Cleveland.

San Antonio-Austin—March 23

"Audio Semiconductor Circuits, D. Meyer, Southwest Research Institute, San Antonio.

San Diego—March 29

"Basic Requirements of Electronic Organs," V. Smith, Veesmith Studios, San Diego.

Audio and Broadcasting

Philadelphia—April 27

"RCA RT-21 Professional Audio Tape Recorder," R. V. Hedlund, RCA, Camden, N. J.

Automatic Control

Chicago—April 13

"Symbolic Control of Automatic Tools," S. Hori, Armour Research Foundation, Chicago.

Dallas-Ft. Worth—April 17

"The Engineer's Stake in Automation," F. R. Summers, Westinghouse, Houston.

Dallas-Ft. Worth—April 3

"Remote Control System for a Drone Helicopter," D. C. Gorsuch, Bell Helicopter, Hurst, Tex.

Los Angeles—April 10

"Use of Parameter Influence Programming in Computer Analysis of Nonlinear Control Systems," H. F. Meissinger, Hughes Aircraft Co., Culver City.

Los Angeles—March 13

"Basic Ballistics," D. L. Pittman, Douglas Aircraft Co., Santa Monica.

Philadelphia—March 20

"Adaptive Systems and Control," Dr. D. W. C. Shen, Moore School of Electrical Engineering.

Pittsburgh—February 26

"Computer Techniques for Control Systems," Dr. M. Selberger, IBM, Yorktown Hts., N. Y.

Pittsburgh—February 19

"An Introduction to Liapunov's Direct Method and Pontryagin's Maximum Principle," Dr. C. C. Li, University of Pittsburgh.

Schenectady—March 20

"Future Air Traffic Control Systems," R. L. Biermann, Federal Aviation Agency.

BIO-MEDICAL ELECTRONICS

Baltimore—April 16

"Biological Hazards of Microwave Radiation," W. W. Mumford, Bell Telephone Labs., Murray Hill, N. J.

Boston—April 10

"Microradiography as a Tool in Biological Research," Dr. O. Friberg, Mass. General Hospital.

Cleveland—March 21

"Continuous Wave Ultrasonic Flowmeter," F. W. Noble, Nat'l. Heart Institute.

"Status of the Medical Engineer, New and Future," R. L. Bowman, Nat'l. Heart Institute.

Cleveland—February 28

"Some Thoughts on Bio-medical Pattern Recognition," K. Enslein, Brooks Research, Inc., E. Rochester, N. Y.

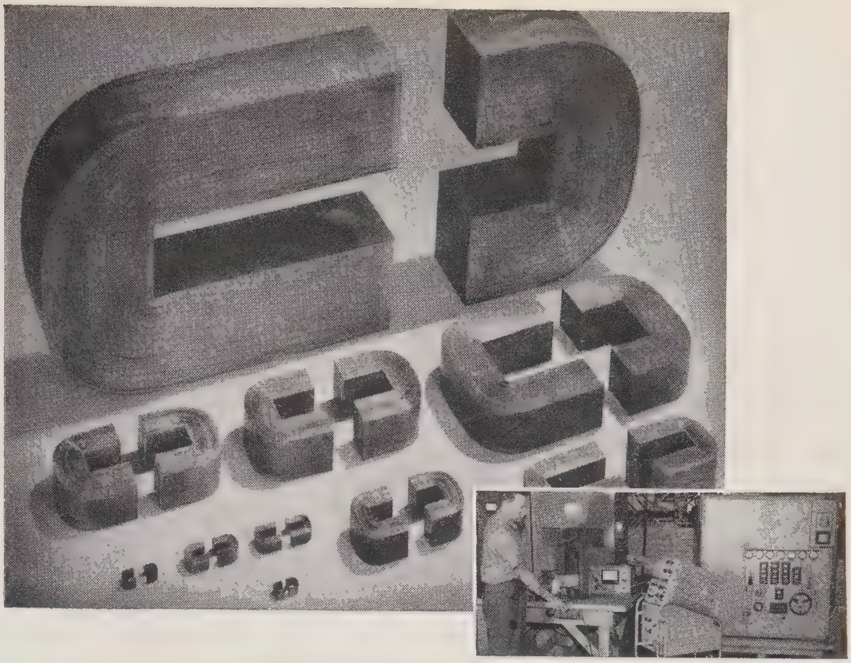
Cleveland—January 31

"Medicine and Isotopes—Total Body Radiation Spectrum," R. Schwartz, M. D., Western Reserve Univ.

Cleveland—December 20

"Opportunities in Medical Electronics; Surgeon's Viewpoint," G. Clowes, M.D.

(Continued on page 68A)



Arnold Pulse Transformer Cores are individually tested under actual pulse conditions

The inset photograph above illustrates a special Arnold advantage: a 10-megawatt pulse-testing installation which enables us to test-prove pulse cores to an extent unequalled elsewhere in the industry.

For example, Arnold 1 mil Silectron "C" cores—supplied with a guaranteed minimum pulse permeability of 300—are tested at 0.25 microseconds, 1000 pulses per second, at a peak flux density of 2500 gausses. The 2 mil cores, with a guaranteed minimum pulse permeability of 600, receive standard tests at 2 microseconds, 400 pulses per second, at a peak flux density of 10,000 gausses.

The test equipment has a variable range which may enable us to make special tests duplicating the actual operating conditions of the transformer. The pulser permits tests at .05, .25, 2.0 and 10.0 microsecond pulse duration, at repetition rates varying anywhere from 50 to 1000 pulses per second.

This is just another of Arnold's facilities for better service on magnetic materials of all description. ● Let us supply *your* requirements.

Here's technical data on ARNOLD SILECTRON CORES

Bulletin SC-107 A contains design information on Arnold Tape Cores wound from Silectron (grain-oriented silicon steel). It includes data on cut C and E cores, and uncut toroids and rectangular shapes. Sizes range from a fraction of an ounce to more than a hundred pounds, in standard tape thicknesses of 1, 2, 4 and 12 mils.

Cores are listed in the order of their power-handling capacity, to permit easier selection to fit your requirements, and curves showing the effect of impregnation on core material properties are included.

4102

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1

New 1N3728 (formerly Rheem RD250), direct replacement
— at about half the price —
for any of more than 250 general purpose
and hv silicon diodes,
is available from Raytheon Distributors coast to coast.

DOES IT AT HALF THE PRICE!

We will be happy to send you the name
of the Raytheon Distributor serving your area.
Please write: Raytheon Company,
Distributor Products Division,
411 Providence Turnpike,
Westwood, Massachusetts

Raytheon Distributors include:

ALABAMA
Birmingham
MG Electrical Equipment Company
FAirfax 2-0449
Mobile
Forbes Electronic Distributors, Inc.
HE 2-7661

CALIFORNIA
Burbank
Valley Electronic Supply Co.
VIctoria 9-3944
Glendale
R. V. Weatherford Co.
VIctoria 9-2471
Hollywood
Hollywood Radio & Electronics, Inc.
HO 4-8321
Inglewood
Newark Electronics Company
ORchard 4-8440
ORegon 8-0441
Los Angeles
California Electronics Supply, Inc.
BRadshaw 2-2124
GRanite 7-1208
Federated Purchaser
BRadshaw 2-8771
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RIchmond 8-2444
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Richey Electronics, Inc.
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Brill Electronics
TE 2-6100
Elmar Electronics
TEmplar 4-3311
Palo Alto
Zack Electronics
DA 6-5432
Riverside
Electronic Supply, Riverside, Inc.
OV 3-8110
Sacramento
Sacramento Electronic Supply Co.
GI 1-4821
San Diego
Kierulff Electronics, Inc.
BR 6-3334
Pabtronics Corp.
CY 8-7224
Radio Parts Company
BE 9-9361
Telrad Electronics
AT 1-7754
San Francisco
Fortune Electronics
UN 1-2434
Santa Ana
Airtronic Sales, Inc.
KImberly 5-9441
Santa Monica
Santa Monica Radio Parts Corp.
EXbrook 3-8231

COLORADO
Denver
Denver Electronic Supply Co.
SKyline 7-3351
Ward Terry Company
AMherst 6-3181

CONNECTICUT
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J. V. Electronics
HObart 9-1310
Stamford
Sun Radio & Electronics, Inc.
DA 5-4336

DISTRICT OF COLUMBIA
Electronic Wholesalers, Inc.
HUdson 3-5200
Empire Electronic Supply Co.
OLiver 6-3300

FLORIDA
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East Coast Electronics, Inc.
FRanklin 1-4636
Electronic Equipment Co., Inc.
NEwton 5-0421
Orlando
Wholesale Radio Parts Co., Inc.
GArden 4-6579
West Palm Beach
Goddard Distributors, Inc.
TEmple 3-5701

ILLINOIS
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Allied Electronics Corporation
TA 9-9100
Newark Electronics Corp.
STate 2-2944

INDIANA
Indianapolis
Graham Electronics Supply Inc.
MElrose 4-8486

LOUISIANA
Baton Rouge
Southern Radio Supply Company, Inc.
DI 3-6658
New Orleans
Southern Radio Supply Company, Inc.
TUlane 2345

MARYLAND
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MUlberry 5-2134

MASSACHUSETTS
Boston
Cramer Electronics, Inc.
WO 9-7700
DeMambro Radio Supply Co., Inc.
AL 4-9000
Lafayette Radio Corp., of Mass.
HUbbard 2-7850
Radio Shack Corp.
RE 4-1000
Cambridge
Electrical Supply Corp.
UNiversity 4-6300

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Detroit
Newark-Ferguson Electronics, Inc.
UN 1-6700

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Ellington Radio, Inc.
FL 3-2769

MISSOURI
Kansas City
Burstein-Applebee Company
BAltimore 1-4266
Walters Radio Supply, Inc.
VA 1-8058
University City
Olive Industrial Electronics
VOlunteer 3-4051

NEW HAMPSHIRE
Concord
Evans Radio
CApital 5-3358

NEW JERSEY
Camden
General Radio Supply Co., Inc.
WO 4-8560 (in Phila.: WA 2-7037)
Mountainside
Federated Purchaser Inc.
AD 2-8200

NEW YORK
Binghamton
Stack Industrial Electronics, Inc.
RA 3-6326
Buffalo
Genesee Radio & Parts Co., Inc.
TR 3-9661
Wehle Electronics, Inc.
TL 4-3270
Elmira
Stack Industrial Electronics, Inc.
RE 3-6513
Ithaca
Stack Industrial Electronics, Inc.
IThaca 2-3221
Mineola, Long Island
Arrow Electronics, Inc.
PIoneer 6-8686
New York City
H. L. Dalis, Inc.
EMpire 1-1100
Milo Electronics Corp.
BEekman 3-2980
Quad Electronics, Inc.
CL 8-9200 (Brooklyn)
Sun Radio & Electronics Co., Inc.
ORegon 5-8600
Terminal-Hudson Electronics, Inc.
CHelsea 3-5200
Utica
Valley Industrial Electronics, Inc.
RA 4-5168
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WHite Plains 9-7715

OHIO
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United Radio, Inc.
CHerry 1-6530
Cleveland
Main Line Cleveland, Inc.
EXpress 1-4944
Pioneer Electronic Supply Co.
SUperior 1-9411
Columbus
Buckeye Electronic Distributors, Inc.
CA 8-3265
Dayton
Srepco, Inc.
BAldwin 4-3871

OKLAHOMA
Tulsa
Radio, Inc.
LU 7-9124
S & S Radio Supply
LU 2-7173

OREGON
Portland
Lou Johnson Company, Inc.
CApital 2-9551

PENNSYLVANIA
Harrisburg
D & H Distributing Co., Inc.
CEdar 6-8001
Philadelphia
Almo Radio Company
WAlnut 2-5918
Powell Electronics, Inc.
SA 4-1900
Radio Electric Service Co.
WAlnut 5-5840
York
Wholesale Radio Parts Co., Inc.
47-1007

TENNESSEE
Knoxville
Bondurant Brothers Company
3-9144

TEXAS
Fort Worth
SWIECO, Inc.
ED 2-7157 (in Dallas: AN 2-5026)

UTAH
Salt Lake City
W. H. Bintz Co.
EMerson 3-5821

VIRGINIA
Norfolk
Priest Electronics
MA 7-4534

WASHINGTON
Tacoma
C & G Electronics Co.
BR 2-3181

WISCONSIN
Milwaukee
Electronic Enterprises, Inc.
GR 6-4144
Electronic Expeditors, Inc.
ED 2-0616

Graybar Electric Company, Inc. — Nationally (see Yellow Pages)

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RAYTHEON 1N3728 CUTS DIODE COSTS IN HALF

New high reliability 1N3728 (formerly Rheem RD250) is direct replacement for more than 250 general purpose and high voltage silicon diodes.

Now you can reduce qualification and specification expenses, lower inventory costs, and obtain higher reliability with the Raytheon/Rheem 1N3728 *Universal* silicon diode. It is priced at less than one-half the average of manufacturer's published prices for the diodes it replaces, and meets or exceeds all tests and specifications for these units.

The 1N3728 features very high voltage with very low leakage. Reverse leakage is specified at nine points, forward current at ten. Replacement of standard 100 and 200 volt diodes with the low cost 550-volt 1N3728 greatly increases the safety margin of the reverse characteristic, substantially reducing the major point of diode failure. Dependable performance is assured by more than two years of testing and field use.

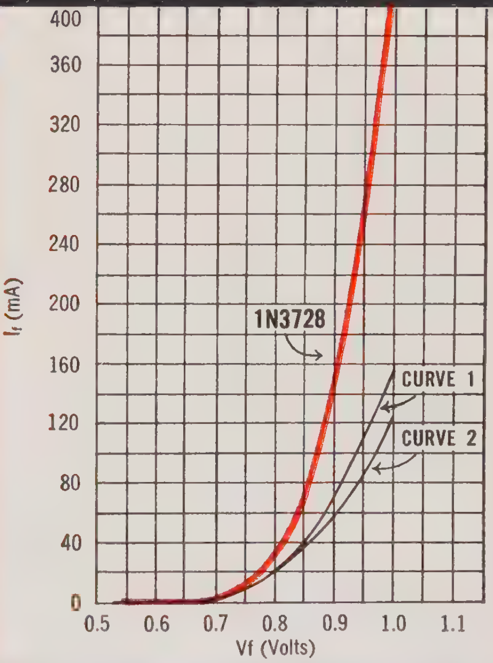
For complete data of the 1N3728, please contact the Raytheon Field Office nearest you, or write Semiconductor Division, 900 Chelmsford Street, Lowell, Massachusetts.

MAXIMUM RATINGS @ 25°C		1N3728	UNIT
Peak rectified current	I_F	650	mA
Average rectified current	I_0	200	mA
Surge current (1 sec.)	i_F (surge)	1000	mA
Pulse current (2μsec. 1% duty cycle)	i_F (pulse)	2000	mA
Power dissipation (derate 1.4 mw/°C)	P_t	250	mW
Operating temperature	T_A	−65 to +200	°C
Storage temperature	T_{stg}	−65 to +200	°C

SPECIFICATIONS	MIN.	TYP.	MAX.	UNIT
Forward Voltage @ 1 mAdc	.61	.64	.68	V
@ 10 mAdc	.72	.75	.80	V
@ 100 mAdc	.84	.87	.98	V
@ 200 mAdc	.88	.92	1.09	V
@ 400 mAdc	.92	.98	1.20	V
Reverse Current @ 20 Vdc				
@ 25°C		.0005	.005	μAdc
@ 100°C		.050	.100	μAdc
@ 150°C		1.00	2.0	μAdc
Reverse Current @ 175 Vdc				
@ 25°C		.010	.025	μAdc
@ 100°C		.150	.500	μAdc
@ 150°C		2.0	5.0	μAdc
Reverse Current @ 400 Vdc				
@ 25°C		.085	.100	μAdc
@ 100°C		.500	1.00	μAdc
@ 150°C		4.0	10.0	μAdc
Saturation Voltage −65°C to +200°C @ 100 μA	500	—	—	Vdc
Saturation Voltage @ 25°C @ 100 μA	550	650	—	Vdc

(SHOWN ACTUAL SIZE)

TYPICAL DIODE FORWARD CHARACTERISTICS



TYPES REPLACED BY 1N3728

Some of the currently-used types replaced by the 1N3728/RD250 are such general purpose, high voltage silicon diodes as:

Type	*Curve*	*Type*	*Curve*	*Type*	*Curve*	*Type*	*Curve*
1N456	2	1N461	2	1N482	1	1N485	1
1N456A	1	1N461A	1	1N482A	1	1N485A	1
1N457	2	1N462	2	1N482B	1	1N485B	1
1N457A	1	1N462A	1	1N483	1	1N486	1
1N458	2	1N463	2	1N483A	1	1N486A	1
1N458A	1	1N463A	1	1N483B	1	1N487	1
1N459	2	1N464	2	1N484	1	1N487A	1
1N459A	1	1N464A	1	1N484A	1	1N488	1
				1N484B	1	1N488A	1

SEMICONDUCTOR DIVISION

RAYTHEON

LOWELL, MASSACHUSETTS

Professional Group Meetings

(Continued from page 65A)

Cleveland—November 29

"Coronary Artery Angiography with Optical Intensifier," B. M. Sones, Cleveland Clinic.

Columbus—March 1

"An Information Processing Model of Human Behavior," Dr. L. Lipetz, Ohio State University Institute for Research and Vision.

Los Angeles—March 15

"Low Level Current Measurements and Their Applications to Biomedicine," W. R. Williams, Applied Physics Corp., Monrovia, Calif.

Memphis—April 4

"Physiological Monitoring in the Space Age," Lt. Comdr. R. Mullin, U. S. N. Recovery Surgeon assigned to Noa during Glenn Flight.

New York—February 20

"An Instrument for Visualizing Internal Procedures with Magnetic Fields," G. R. Nagamatsu, M.D., Metropolitan Hospital Center.

"Expanding Horizons in Urologic Instrumentation," P. C. Richardson, B.E.E., Metropolitan Hospital Center.

North Carolina—March 22

"Computers in Medicine," Dr. H. P. Spencer, Bowman Gray School of Medicine.

"Data Storage," Dr. H. M. Carpenter, Bowman Gray School of Medicine.

Presentation of 3 Problem Areas in which it is hoped some aid may be obtained through electronics, Dr. C. Hendley, Bowman Gray School of Medicine.

Philadelphia—April 5

"Stereoscopic Televised Fluoroscopy," H. M. Stauffer, M.D.; Temple University School of Medicine; G. C. Henny, M.D., Temple University School of Medicine; F. J. Bingley, Philco Corp., Philadelphia; J. F. Fisher, Philco Corp., Philadelphia.

Rochester—April 9

"Fiber Optics-Fundamentals and Limitations," Prof. Robert E. Hopkins, University of Rochester.

"Fiber Optics Applications," J. T. Ferris, Bausch and Lomb, Inc., Rochester.

Rochester—March 12

"The Hospital of the Future: Architecture, Personnel, Instrumentation and Operating Cost Reduction," Dr. G. Radcliffe, Columbus Hospital, Newark, N. J.

Rochester—February 13

"Speech Analysis," F. H. Slaymaker General Dynamics/Electronics, Rochester

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ESTIMATE ITS VALUE

No one can. Magnetic tape recordings may be priceless one moment and through distortion almost useless the next—often impossible or impractical to duplicate. Because loss or distortion of tapes—due to unpredicted magnetic fields—have become increasingly common during shipment or storage, it will pay you to protect them.

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Rochester—January 8

"The Role of the Biomedical Engineer in the Hospitals," Dr. D. A. Holaday, University of Chicago.

Rochester—December 13

Dr. W. A. Clark, M.I.T. Lincoln Lab., Cambridge

San Francisco—April 17

"Experimental Biology in Space," Dr. R. S. Young, Ames Res. Lab., Moffett Field, Calif.

BROADCASTING

Cleveland—April 18

"An All Transistor UHF-VHF Field Strength Meter," C. S. Bidlack, Smith Electronic, Inc., Cleveland; J. F. Dobosy, Perry Briggs Co.

Cleveland—January 18

"High Temperature High Power R.F. Transmission Lines," H. J. Woodbury, Andrew Corp., Chicago.

Florida West Coast—March 28

"Automatic Transmitter Logging," W. C. Morgan, Minneapolis-Honeywell, Tampa, Fla.

Pittsburgh—April 16

"Satellite Communications," T. A. Graul, Bell Telephone Co. of Pennsylvania, Pittsburgh.

Twin Cities—March 14

"TV Automation," F. Street, KSTP TV, Minneapolis/St. Paul.

Twin Cities—January 31

"Frequency Modulation Multiplex Systems," R. W. Schoening, N. W. Television and Electronic Inst., Minneapolis.

Twin Cities—December 19

"Satellite Communications," F. S. Hird, N. W. Bell Telephone Co.

CIRCUIT THEORY

Albuquerque-Los Alamos—April 16

"Filters—Optimum and Ideal," Dr. A. H. Koschmann; University of New Mexico.

San Antonio-Austin—January 18

"The Dynamic Behavior of Negative Resistance Devices," Dr. C. O. Harbourt, University of Texas.

CIRCUIT THEORY and INFORMATION THEORY

Omaha-Lincoln—March 23

"Unsolved Problems in Information Theory," Dr. G. L. Turin, University of California, Berkeley.

Communications Systems

Boston—May 15

"Dyna-Soar Communications," L. B. Garrett, Jr., RCA, Camden.

Boston—March 20

"New Trends in Communications," U. S. Berger, Bell Telephone Labs.

San Francisco—March 28

"An Advanced New Military Multiplexing System—Can It Be Used Economically for Commercial Applications," T. C. Bean, Lenkurt Electric Co., San Carlos, Calif.

Other activities: Inspection of AN/FCC-17 600 channel multiplex equipment and inspection trip of a portion of Lenkurt production facilities.

Toronto—April 16

"Direct Distance Dialing," C. A. Marshall, P. Eng., Automatic Electric (Canada), Ltd.

Washington, D. C.—March 16

"NASA Plans in Communication Satellites," L. Jaffe, NASA.

Communications Systems and Microwave Theory and Techniques

Omaha-Lincoln—March 28

"From Morse to Microwave," P. D. Patterson, Western Union Telegraph Co., Omaha.

Communications Systems and Military Electronics

Syracuse—April 17

"Project Mercury, Worldwide Communications Network," C. W. Schramm, Bell Telephone Labs., Whippany, N. J.

Communications Systems and Vehicular Communications

Omaha-Lincoln—April 19

"The A-B-C of Dataphone," R. A. Ryerson, K. L. Powell, and J. Orr, Northwestern Bell Telephone Co., Omaha.

Component Parts

Baltimore—April 10

"Integrated Circuitry," Dr. P. B. Myers, Martin-Marietta, Baltimore.

New York—December 6

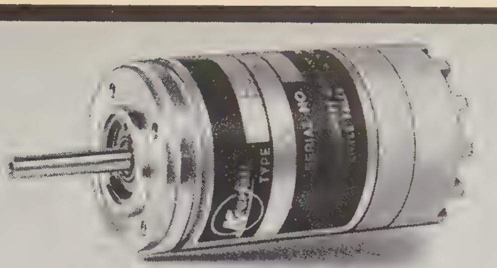
"Optimum Potentiometer Performance Through Compromise," R. Quinn, Fairchild Control.

"The Case for Improved Specifications for Precision Potentiometers," A. Lobert, Bendix Eclipse Pioneer Div.

"Military Specifications for Precision Potentiometers," S. Grubman, USASMA, Ft. Monmouth, N. J.

Panel moderator: J. Reed, Adler Electronics.

(Continued on page 70A)



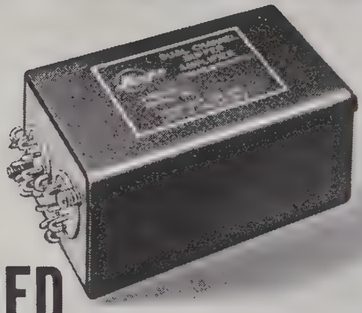
SIZE 11 WINDING-COMPENSATED SYNCHRO RESOLVER

Precision, lightweight, high-accuracy components with applications in analog computers and automatic control systems. The compensator winding provides feedback voltage for a resolver isolation amplifier; the feedback loop automatically adjusts to compensate for temperature and frequency variations. Function error of the R980-018 is only 0.1%. A compatible transistorized amplifier, Kearfott number S3100-01A, is available.

	Part Number	5R980-41	CR9 0980 001 R980-018
CHARACTERISTICS	Excitation (volts) (max.)	60	26
	Frequency (cps)	400	400
	Total Null Voltage (mv)	25	10
	Max. Error from E.Z. (minutes)	5	5
	Operating Temp. Range (°C)	−55 to +125	−55 to +125

For complete data write Kearfott Division, General Precision, Inc., Little Falls, New Jersey.

KEARFOTT



DUAL-CHANNEL TRANSISTORIZED BUFFER AMPLIFIERS

These high-performance units are designed to drive Kearfott's Size 11 R980 winding-compensated synchro resolvers. The amplifier-resolver combination has stable gain characteristics and negligible phase shift through an ambient temperature range of −50°C to +85°C. Extremely high resistance to shock and vibration. Meet environmental requirement of MIL-E-5272.

	Part Number	S3100-01
CHARACTERISTICS	Number of Inputs	4 per channel
	Input Impedance (ohms resistive at 25°C)	100,000
	Voltage Gain	1±0.0005
	Phase Shift (rotor output to input at 25°C)	less than 15 min.
	Max. Signal Output Voltage	16 volts
	Gain Stability Over Operating Temp. Range	1±0.05%

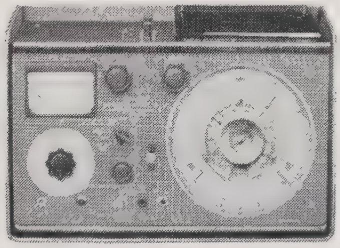
For complete data write Kearfott Division, General Precision, Inc., Little Falls, New Jersey.

GP GENERAL PRECISION

1/4% ACCURACY

WITH DIRECT READOUT

NEW
UNIVERSAL BRIDGE



Model 1313
Price $590

MEASURES:
L: .... 1μH to 110H
C: .... 1pF to 110μF
R: .... 0.01Ω to 110MΩ
With ¼% Accuracy
EXCEPTIONAL RESOLUTION
5,000 divisions per range
BUILT-IN 1 AND 10Kc OSC/DET
100 cps to 20 Kc with ext. osc.
Automatic dial mechanism eliminates multiplying factors, giving surprising ease of use.

ASK FOR FULL DESCRIPTION **NOW**

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INSTRUMENTS
DIVISION OF ENGLISH ELECTRIC CORPORATION
111 CEDAR LANE • ENGLEWOOD, NEW JERSEY
MAIN PLANT: ST. ALBAN'S, ENGLAND

Professional Group Meetings

(Continued from page 69A)

New York—October 5

S. Sherr, Internat'l. Resistor Co., Philadelphia; A. Stansbury, Quan-Tech, Boonton, N. J., J. Curtis, Corning Glass.

COMPONENT PARTS and ELECTRON DEVICES

Omaha-Lincoln—May 10

"Progress in the Field of Liquid Breakdown during the last Decade," Dr. A. H. Sharbaugh, General Electric Co., Schenectady.

Omaha-Lincoln—April 11

"Tour of Western Electric Cable Plant," and "The Fastax Movie Camera," (Demonstration and Film), R. D. Barnett, A. E. Hartman, P. Sengpiehl; J. L. Burke, L. W. Myers, Western Electric Co., Omaha.

ELECTRON DEVICES

Boston—April 12

"Equipment Builders View Micro and Integrated Electronics," R. H. Baker, M.I.T., Lincoln Lab.; C. P. Pfaelzer, Raytheon, Waltham, R. R. Fidler, Sylvania, Needham.

Boston—March 8

"Electron Beam-Plasma Interaction," L. D. Smullin, M.I.T.

Los Angeles—January 8

"Characteristics of Semiconductor Photosensitive Devices," J. Hodges, Texas Instruments.

Los Angeles—November 29

"Solid State Electronic Systems," Dr. H. W. Welch, Jr., Motorola, Inc., Scottsdale, Ariz.

Los Angeles—October 19

"The Electronic Blackboard—Its Evolution and Application." N. H. Lehrer, Hughes Res. Labs., Malibu, Calif.

Philadelphia—March 22

"R. F. Applications of Backward Diodes," W. Follmer, Philco Corp., Blue Bell, Pa.

Syracuse—March 20

"Reliability," Moderator, W. Waldron; panel members: C. Zierdt, R. Quick, R. Patch, E. Stabler, General Electric, Syracuse.

Washington D. C.—April 2

"Solar Cell Development and Applications," K. D. Smith, Bell Telephone Labs., Murray Hill.

ELECTRON DEVICES and MICROWAVE THEORY AND TECHNIQUES

Los Angeles—April 5

"VTM's," Dr. M. Weinstein, General Electric Co.

"Tunnel Diode Circuits in the Microwave Region," C. L. Cuccia, RCA, Los Angeles.

San Francisco—March 7

"New Techniques in Generation of Millimeter and Sub-millimeter Waves," P. Colemon, University of Illinois.

San Francisco—February 28

"Millimeter Transmission Line and Antenna Design," A. J. Simmons, Technical Research Group, Inc.

"Foster Scanner," C. A. Hacking, Sylvania, Mountain View, Calif.

ELECTRONIC COMPUTERS

Baltimore—March 21

"Packaging of the 'MADDAM' Computer," S. Schneider, Burroughs Corp, Paoli, Pa.

Boston—March 21

"Current State of Computer Technology in Japan," E. Goto, University of Tokyo.

Boston—February 15

"Mass Memory Devices," T. Brill, Honeywell Data Processing Div.

Boston—January 10

"Satin System," D. L. Bailey and J. L. Morey, Mitre Corp.

Boston—December 5

"On Forgery," M. Eden, M.I.T.

Ft. Worth—March 27

"Problem Definition and Translation for a Computer," G. D. Pirtle, IBM.

Ft. Worth—March 20

"Fundamentals of Programming and Programming Systems," R. J. Bell, IBM.

Ft. Worth—March 13

"Digital Computer Component Logic," J. R. Stumph, IBM.

Ft. Worth—March 6

"Orientation to Digital Computers," P. H. Green, IBM.

Philadelphia—April 10

"The Operational Use of Digital Computers in the Electrical Power Industry," J. W. Hoag, Minneapolis-Honeywell; A. C. Hartranft and J. R. Stauffer, Philadelphia Electric Co.

Other activities: Tour and demonstration of the Digital Computer directed Economic Dispatch System of the Philadelphia Electric Co.

(Continued on page 72A)

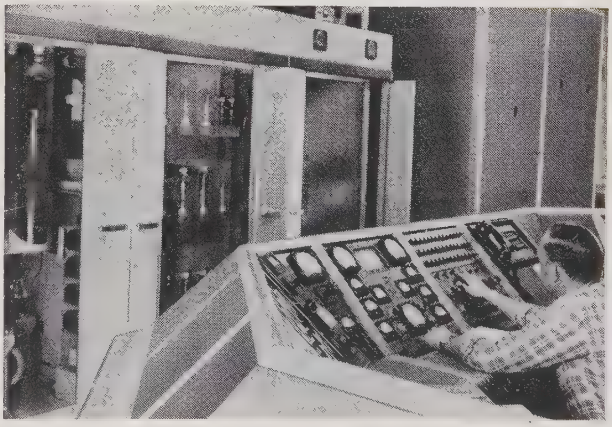
CAPTURING SOLAR STORMS WITH RADAR...

new data for man's exploration of space

Using the world's most powerful VHF radar system, MIT Lincoln Laboratory Solar Radar Site near El Campo, Texas is gathering new data on the sun's corona; measuring the origin and intensity of violent coronal activity which ejects high energy particles into the solar system . . . a serious hazard to space travel.

Heart of the radar is a 500,000 watt VHF transmitter designed and built by Continental Electronics, specialists in super power transmitters. Operating at frequencies near 38 megacycles per second with a continuous output power of 500,000 watts, this transmitter is ten times more powerful than the largest commercial broadcast transmitter in the United States.

Increasing our scientific knowledge of the factors affecting space travel, the El Campo project is jointly sponsored by the U. S. Army, Navy, and Air Force.



Partial view of the transmitter, console and control panel for the radar system.

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Professional Group Meetings

(Continued from page 70A)

Philadelphia—March 13

"The Operational Characteristics of the Com Log Net System," H. P. Guerber, RCA, Camden.

San Francisco—March 27

"Micro-Programming and Its Modifications," Dr. H. M. Semarne, Consultant of Computer Applications.

Santa Ana—April 26

"Computer Generated Display Systems and Techniques," moderator: L. C. Hobbs, Hobbs Associates; speakers: R. von Buelow, Systems Development Corp.; H. Hendrickson, Ford Motor Co.; R. Koster, Thompson-Ramo Wooldridge Corp.; R. Asher, Hughes Aircraft Co.

Santa Ana—March 22

"The SATURN Automatic Checkout System," B. Feild and Joseph Heskin, Packard Bell Computer Corp.

Syracuse—February 28

"Various Approaches to Artificial Intelligence," Dr. P. M. Lewis, II, General Electric Res. Lab.

Twin Cities—November 16

"High Speed Digital Devices," M. Macaulay, Data Display, St. Paul.

Washington, D. C.—March 14

"Table Lookup Computers," J. Griffith, IBM Federal System Div.

Washington, D. C.—February 7

"Field Trip to View Optical Character Recognition Machines," J. Rabinow, Rabinow Engineering Co., Rockville, Md.

Washington, D. C.—November 1

"Application of Computer Systems to Air Traffic Control," A. Brown, Federal Aviation Agency.

Washington, D. C.—October 4

"The AN/UYK 1 Stored Logic Computer," P. C. Stahl, Ramo-Wooldridge, Canoga Pk., Calif.

ENGINEERING MANAGEMENT

Baltimore—April 12

"Engineering Organization Patterns," C. McMullen and E. D. Hart, Bendix Radio; A. Stern, Martin Co.; D. Tashyian, Westinghouse.

Baltimore—March 22

"PERT—A Tool for Program Management," Y. Nakayama, Dept. of Navy, Washington, D. C.

Buenaventura—March 8

"Program Evaluation and Review Technique (PERT)," E. E. Dawson, Hq. Pacific Missile Range, Point Mugu, Calif.

Buenaventura—January 29

"New Trends in Management" T. E. Hanes, U. S. Naval Missile Center, Point Mugu, Calif.

New York—November 15

"Management of Intra and Inter-Systems Coordination as Related to RF Interference," Dr. J. H. Vogelman, Capehart Corp.

New York—October 11

"The Use of Computers in Project Management as Applied to PERT," W. Ferr, Dept. of Navy, Washington, D. C.

San Francisco—March 21

"PERT, a New and Valuable Tool," R. M. T. Young, Lockheed Missile and Space Co., Sunnyvale, Calif.

Washington D. C.—March 12

"Creative People in Research and Development," Dr. H. Brown, Harris Res. Labs. (Gillette) Washington, D. C.

ENGINEERING WRITING AND SPEECH

Boston—May 8

"How to Write for Technical Journals," W. F. Bushor, McGraw-Hill Publishing Co., New York, N. Y.

Boston—April 26

Panel discussion: "Publications Management," moderator: F. T. Van Veen, General Radio, Concord, Mass.; panelists: R. D. Eames, Raytheon, Wayland; W. H. Hurd, RCA Burlington; D. W. Kerr, S. Gunnar Myrbeck and Co., Quincy, Mass.

Los Angeles—April 4

"Workshop Session on 'Giving the Military What it Wants to Read'," A. Scarpa, Army Signal Corps; A. A. Konkle, A. F. Systems Command.

Syracuse—March 6

Forum "The Aims and Purposes of PGEWS and the New Chapter," Dr. R. E. Gildersleeve, C. A. Dostal, A. B. Lurie, and Dr. N. Schwartz.

Twin Cities—November 21

"Stage Fright," Film.

"The Engineer's Power of Argument," D. Larson, Remington Rand Univac, St. Paul.

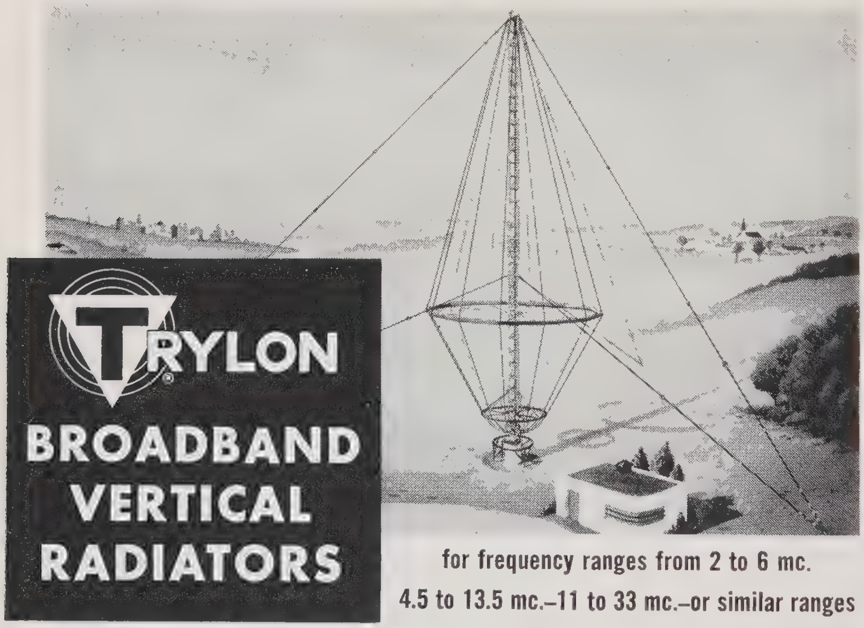
HUMAN FACTORS IN ELECTRONICS

Los Angeles—March 13

"Introduction of Advanced Technology to Emerging Nations: Economic, Political and Social Factors," T. Loeber, U.C.L.A.

"Education and Learning," W. Orr, U.C.L.A.

(Continued on page 76A)



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The basic shape of things to come . . . in silicon planar transistors

Since the introduction of the Motorola silicon epitaxial Star* planar transistor, many users have commented on its performance. One firm is using this new transistor "... because of its outstanding gain at only 2.5 μA."

Another company reports the highest gain at high current levels of any type previously tried. Both users made note of the Star planar's unusually high frequency response.

Why should the pointed geometry of the Star transistor make possible a device so universally applicable? First, the four-pointed pattern provides a high emitter perimeter-to-area ratio necessary for combined high current capability and high frequency performance. Second, the combination of this ratio, the circular symmetry, the tapered "fingers," and one central bonding area all contribute to giving the Star transistor advantages over all other geometries proposed for a high frequency, low or high current transistor.

From a practical viewpoint, the pointed pattern has called for abilities in precise micromanipulation, photo-resist masking, and alignment techniques never before achieved on a production scale. Only by keeping the emitter area in the center of the pattern as small as possible (barely larger than the area required for the emitter lead) has it been possible to achieve such frequency response. And the spacing between emitter and base is only .0005".

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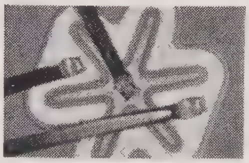

What about other variations?

Although for most applications, the four-pointed pattern is the ideal geometry, there are special requirements for higher current and higher power devices. These requirements are being met by the new Motorola-developed industry standard Snowflake* transistor (six points) and five pointed structures which provide substantially higher current capability than even the Star transistor. As is usually the case in transistor design, one is often forced to compromise, and in spite of our enthusiasm over the new Motorola Snowflake transistor, it appears that in its field of application the Motorola Star transistor is unequalled by any device that is likely to be developed for some time to come.

The Basic Shape Of Things To Come is here already ... the Motorola Silicon Epitaxial "Star" Planar Transistor. If you haven't tried these devices in your most demanding circuits, we'd welcome the opportunity of proving their superiority. Simply call your nearest Motorola semiconductor field representative and request samples of the Star transistor. And, if you have a special need for even higher current devices, write on your letterhead for early development samples of Motorola's silicon Snowflake transistor to: *Technical Information Center — Motorola Semiconductor Products Inc., 5005 East McDowell Road, Phoenix 8, Arizona.*

*STAR and SNOWFLAKE are trademarks of Motorola, Inc.
Patents applied for

29 Fields of Special Interest-

The 29 Professional Groups are listed below, together with a brief definition of each, the name of

Aerospace and Navigational Electronics

Annual fee: $3.

The application of electronics to operation and traffic control of aircraft and to navigation of all craft.

Mr. S. H. Dodington, Chairman, ITT Labs., Nutley, N.J.

43 Transactions, *9, Vol. 2, No. 3; Vol. 4, No. 1, 2, 3; Vol. 5, No. 2, 3, 4; Vol. 6, No. 1, 2, 4; Vol. 7, No. 1, 2, 3, 4; Vol. 8, No. 1, 2, 3, 4; Vol. 9, No. 1.

Antennas and Propagation

Annual fee: $6.

Technical advances in antennas and wave propagation theory and the utilization of techniques or products of this field.

Dr. Harry Fine, Chairman, Applied Propagation Branch FCC, Washington, D.C.

50 Transactions, *Vol. AP-2, No. 2; AP-4, No. 4; AP-5, No. 1-4; AP-6, No. 1, 2, 3, 4; AP-7, No. 1, 2, 3, 4; AP-8, No. 1, 2, 3, 4, 5, 6; AP-9, No. 1, 2, 3, 4, 5, 6; AP-10, No. 1, 2, 3.

Audio

Annual fee: $2.

Technology of communication at audio frequencies and of the audio portion of radio frequency systems, including acoustic terminations, recording and reproduction.

Dr. Robert W. Benson, Chairman, Elec. Eng. Dept., Vanderbilt University, Nashville 5, Tenn.

64 Transactions, *Vol. AU-1, No. 6; *Vol. AU-2, No. 4; Vol. AU-3, No. 1, 3, 5; Vol. AU-4, No. 1, 5-6; Vol. AU-5, No. 1, 2, 3, 4, 5, 6; AU-6, No. 1, 2, 3, 4, 5, 6; AU-7, No. 1, 2, 3, 4, 5, 6; AU-8, No. 1, 2, 3, 4, 5, 6; AU-9, No. 1, 2, 3, 4, 5, 6; AU-10, No. 1, 2.

Automatic Control

Annual fee: $4.

The theory and application of automatic control techniques including feedback control systems.

Mr. Louis B. Wadel, Chairman, 3546 Caruth Blvd., Dallas 25, Tex.

18 Transactions, PGAC-3-4-5-6, AC-4, No. 1, 2, 3; AC-5, No. 1, 2, 4; AC-6, No. 1, 2, 3; AC-7, No. 1, 2.

Bio-Medical Electronics

Annual fee: $4.

The use of electronic theory and techniques in problems of medicine and biology.

Dr. O. H. Schmitt, Chairman, Univ. of Minn., Minneapolis, Minn.

25 Transactions, 8, 9, 11; ME-6, No. 1, 3, 4; ME-7, No. 2, 4; BME-8, No. 2, 3, 4; BME-9, No. 1, 2.

Broadcast & Television Receivers

Annual fee: $4.

The design and manufacture of broadcast and television receivers and components and activities related thereto.

Mr. John F. Bell, Chairman, Zenith Radio Corp., 6001 W. Dickens Ave., Chicago 39, Ill.

31 Transactions, *7, 8; BTR-1, No. 1-3, BTR-2, No. 1-2-3; BTR-3, No. 1-2; BTR-4, No. 2, 3-4; BTR-5, No. 1, 2; BTR-6, No. 1, 2, 3; BTR-7, No. 1, 2, 3; BTR-8, No. 1.

Broadcasting

Annual fee: $2.

Broadcast transmission systems engineering, including the design and utilization of broadcast equipment.

Mr. Raymond F. Guy, Chairman, 264 Franklin St., Haworth, N.J.

22 Transactions, No. 10, 11, 12, 13, 14; BC-6, No. 1, 2, 3; BC-7, No. 1, 2, 3, 4, BC-8, No. 1.

Circuit Theory

Annual fee: $4.

Design and theory of operation of circuits for use in radio and electronic equipment.

Dr. James H. Mulligan, Jr., Chairman, College of Eng., New York University, New York 53, N.Y.

37 Transactions, CT-4, No. 3-4; CT-5, No. 1, 2, 3; CT-6, No. 1, 2, 3, 4; CT-7, No. 1, 2, 3, 4; CT-8, No. 2, 3, 4; CT-9, No. 1.

Communications Systems

Annual fee: $4.

Radio and wire telephone, telegraph and facsimile in marine, aeronautical, radio-relay, coaxial cable and fixed station services.

Mr. Ralph L. Marks, Chairman, Rome Air Dev. Center, Griffiss AFB, N.Y.

24 Transactions, CS-5, No. 2, 3; CS-6, No. 1, 2; CS-7, No. 1, 3, 4; CS-8, No. 1, 2, 3, 4; CS-9, No. 1, 2, 3, 4.

Component Parts

Annual fee: $3.

The characteristics, limitation, applications, development, performance and reliability of component parts.

Dr. Louis Kahn, Chairman, Astron Corp., 255 Grant Ave., East Newark, N.J.

28 Transactions, CP-4, No. 1, 2, 3, 4; CP-5, No. 2, 3, 4; CP-6, No. 1, 2, 3, 4; CP-7, No. 1, 2, 3, 4; CP-8, No. 2, 3, 4; CP-9, No. 1, 2.

Education

Annual fee: $3.

To foster improved relations between the electronic and affiliated industries and schools, colleges, and universities.

Mr. George E. Moore, Chairman, Westinghouse Electric Corp., East Pittsburgh, Pa.

17 Transactions, Vol. E-1, No. 3, 4; E-2, No. 1, 2, 3, 4; E-3, No. 1, 2, 3, 4; E-4, No. 1, 2, 3, 4; E-5, No. 1.

Electron Devices

Annual fee: $5.

Electron devices, including particularly electron tubes and solid state devices.

Mr. R. W. Sears, Chairman, Belcom Inc., 1737 L St. N.W., Washington, D.C.

38 Transactions, *Vol. ED-1, No. 4; ED-3, No. 2, ED-4, No. 3, 4; ED-5, No. 2, 3, 4; ED-6, No. 3; ED-7, No. 2, 3, 4; ED-8, No. 1, 3, 4, 5, 6; ED-9, No. 1, 2.

Electronic Computers

Annual fee: $4.

Design and operation of electronic computers.

Mr. Walter L. Anderson, Chairman, General Kinetics Inc., So. Arlington, Va.

41 Transactions, EC-6, No. 2, 3; EC-7, No. 1, 2, 3, 4; EC-8, No. 1, 2, 3, 4; EC-9, No. 1, 2, 3, 4; EC-10, No. 2, 3, 4; EC-11, No. 1.

Engineering Management

Annual fee: $3.

Engineering management and administration as applied to technical, industrial and educational activities in the field of electronics.

Mr. E. G. White, Chairman, Warwick Mfg. Co., 7300 N. Lehigh Ave., Chicago 31, Ill.

25 Transactions, EM-4, No. 1, 3, 4; EM-5, No. 1-4; EM-6, No. 1, 2, 3; EM-7, No. 1, 2, 3; EM-8, No. 1, 2, 3, 4; EM-9, No. 1.

Engineering Writing and Speech

Annual fee: $3.

The promotion, study, development, and improvement of the techniques of preparation, organization, processing, editing, and delivery of any form of information in the electronic-engineering and related fields by and to individuals and groups by means of direct or derived methods of communication.

Mr. John M. Kinn, Jr., Chairman, IBM Journal, 545 Madison Ave., New York, N.Y.

10 Transactions, Vol. EWS-1, No. 2; EWS-2, No. 1, 2, 3; EWS-3, No. 1, 2; EWS-4, No. 2, 3.

THE INSTITUTE OF RADIO

-IRE's 29 Professional Groups

the group chairman, and publications to date.

* Indicates publications still available

Geoscience Electronics

Annual fee: None

Research and development in electronic instrumentation for geophysics and geochemistry, especially gravity measurements, seismic measurements, magnetics, well-logging, space exploration, meteorology, oceanography, etc.

Mr. Robert W. Olson, Texas Instruments Co., Dallas, Tex.

Human Factors in Electronics

Annual fee: $3.

Development and application of human factors and knowledge germane to the design of electronic equipment.

Dr. Albert S. Jackson, Chairman, 111 S. Pittsburgh Ave., Ventnor, N.J.

5 Transactions, HFE-1, No. 1, 2; HFE-2, No. 2; HFE-3, No. 1.

Industrial Electronics

Annual fee: $3.

Electronics pertaining to control, treatment and measurement, specifically, in industrial processes.

Mr. J. E. Eiselein, Chairman, RCA Victor Div., Camden, N. J.

17 Transactions, *PGIE 3, 5, 6, 7, 8, 9, 10. 11; IE-7, No. 1, 2, 3; IE-8, No. 1, 2; IE-9, No. 1.

Information Theory

Annual fee: $4.

The theoretical and experimental aspects of information transmission, processing and utilization.

Dr. George L. Turin, Chairman, Dept. of E.E., Univ. of California, Berkeley 4, Calif.

34 Transactions, PGIT-4, IT-1, No. 3; IT-3, No. 1, 2, 3; IT-4, No. 1, 3, 4; IT-5, No. 1, 2, 3, 4; IT-6, No. 1, 4, 5; IT-7, No. 1, 3, 4; IT-8, No. 1, 2, 3.

Instrumentation

Annual fee: $3.

Measurements and instrumentation utilizing electronic techniques.

Mr. L. D. McLellan, Chairman, Hughes Aircraft Co., Redondo Beach, Calif.

21 Transactions, PGI-4, Vol. 1-6, No. 2, 3, 4; Vol. 1-7, No. 1, 2; Vol. 1-8, No. 1, 2; Vol. 1-9, No. 1, 2, 3; Vol. 1-10, No. 1, 2.

Microwave Theory and Techniques

Annual fee: $4.

Microwave theory, microwave circuitry and techniques, microwave measurements and the generation and amplification of microwaves.

Mr. Seymour B. Cohn, Chairman, Rantec Corporation, 23999 Ventura Blvd., Calabasas, Calif.

42 Transactions, MTT-4, No. 3; MTT-5, No. 3, 4; MTT-6, No. 1, 2, 3, 4; MTT-7, No. 2, 3, 4; MTT-8, No. 1, 3, 4, 5, 6; MTT-9, No. 1, 3, 4, 5, 6; MTT-10, No. 1, 2.

Military Electronics

Annual fee: $4.

The electronics sciences, systems, activities and services germane to the requirements of the military. Aids other Professional Groups in liaison with the military.

Mr. Edward N. Dingley, Jr., Chairman, Electronic Communications, Inc., 1501-72 St. N., Saint Petersburg 10, Fla.

15 Transactions, MIL-1, No. 1; MIL-2, No. 1; MIL-3, No. 2, 3, 4; MIL-4, No. 2-3, 4; MIL-5, No. 1, 3, 4; MIL-6, No. 1.

Nuclear Science

Annual fee: $3.

Application of electronic techniques and devices to the nuclear field.

Mr. W. A. Higinbotham, Brookhaven Natl. Lab., Upton, L.I., N.Y.

24 Transactions, NS-1, No. 1; NS-4, No. 2; NS-5, No. 1, 2, 3; NS-6, No. 1, 2, 3, 4; NS-7, No. 1, 2-3, 4; NS-8, No. 1, 2, 3, 4; NS-9, No. 1, 2.

Product Engineering & Production

Annual fee: $2.

New advances and materials applications for the improvement of production techniques, including automation techniques.

Mr. John W. Trinkaus, Chairman, Sperry Gyroscope Co., Mail Station 1A36, Great Neck, L.I., N.Y.

11 Transactions, No. 3, 4, 5, 6; PEP-5, No. 1, 2, 3, 4; PEP-6, No. 1.

Radio Frequency Interference

Annual fee: $2.

Origin, effect, control and measurement of radio frequency interference.

Mr. Herman Garlan, Chairman, Federal Communications Comm., Wash., D.C.

5 Transactions, RFI-1, No. 1, RFI-2, No. 1, RFI-3, No. 1; RFI-4, No. 1, 2.

Reliability and Quality Control

Annual fee: $3.

Principles and practices used in reliability and quality engineering of electronic products.

Mr. L. J. Paddison, Chairman, Sandia Corp., Sandia Base, Albuquerque, N.M.

23 Transactions, 11, 12, 13, 14, 15; RQC-9, No. 1, 2, 3; RQC-10, No. 2, 3; RQC-11, No. 1.

Space Electronics and Telemetry

Annual fee: $3.

The control of devices and the measurement and recording of data from a remote point by radio.

Mr. H. B. Riblet, Chairman, Applied Physics Lab., Johns Hopkins Univ., Silver Spring, Md.

21 Transactions, TRC-1, No. 2-3; TRC-2, No. 1; TRC-3, No. 2, 3; TRC-4, No. 1; SET-5, No. 1, 2, 3, 4; SET-6, No. 1, 2, 3-4; SET-7, No. 1, 2, 3, 4; SET-8, No. 1.

Ultrasonics Engineering

Annual fee: $2.

Ultrasonic measurements and communications, including underwater sound, ultrasonic delay lines, and various chemical and industrial ultrasonic devices.

Mr. Allen H. Meitzler, Chairman, 12 Harding Road, Morristown, N.J.

10 Transactions, PGUE, 5, 6, 7; UE-7, No. 1, 2; UE-8, No. 1.

Vehicular Communications

Annual fee: $3.

Communications problems in the field of land and mobile radio services, such as public safety, public utilities, railroads, commercial and transportation, etc.

Mr. Richard P. Gifford, Chairman, General Electric Co., Lynchburg, Va.

18 Transactions, 5, 8, 9, 10, 12, 13; Vol. VC-9, No. 1, 2, 3; Vol. 10, No. 1, 2.

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Professional Group Meetings

(Continued from page 72A)

Industrial Electronics

Omaha-Lincoln—April 26

"New Developments in Lighting," T. C. Sidlo, General Electric, Kansas City.

Tour, Line Dispatching Center, Omaha Public Power District; L. Shalla and J. Jelinek, Omaha Public Power District.

Information Theory

Baltimore—April 4

"Applications of Information Theory to Radar," Dr. M. I. Skolnik, Electronic Communications, Inc., Timonium, Md.

Boston—February 6

"Syntactic Analysis in Russian and English," A. Oettinger, Harvard University.

Boston—December 5

"On Forgery," M. Eden, M.I.T.

Instrumentation

San Francisco—April 11

"Overall Considerations for System Design," J. Cunningham, Systron-Donner; J. Hussey, independent consultant.

Washington, D. C.—May 7

"Modularized, Automated Measurements," D. Boyle, Natl. Bureau of Standards, Washington, D. C.

Microwave Theory and Techniques

Boston—March 21

"Plasma-Covered Antennas," G. Meltz and R. A. Shore, AFCRL, Bedford, Mass.

"Phase Steering by Digitally Controlled Time Delays," J. Duffy, Sylvania, Waltham, Mass.

Chicago—April 13

"Ultramicrowave Research at University of Illinois," Dr. M. D. Sirkis, University of Illinois.

Los Angeles—March 20

"Technique for Measuring of Microwave Frequency and Phase Modulation," S. Rosen, Rantec, Calabas, Calif.

Omaha-Lincoln—April 30

"Lasers: Theory, Bibliography and Demonstration," F. G. Suffield, Hughes Aircraft, Culver City.

Tokyo—November 29

"The Application of Microwave Faraday Rotation to Semi-Conductors and Magnetic Materials," Prof. A. M. Portis, Osaka University.

Washington, D. C.—April 12

"Radar Guided Automobiles," Y. Chu, Melpar, Inc., Falls Church, Va.

Washington D. C.—March 19

"Western European Advances in Electronics," G. Goudet, Laboratoire Centrale de Telecommunications, Paris.

Washington, D. C.—February 13

"Microwave Advances at Diamond Ordnance Fuze Laboratory," C. D. Hardin, J. McDade, and R. Garver, DOFL, Washington, D. C.

Military Electronics

Baltimore—March 22

"PERT—A Tool for Program Management," Y. Bakayama, Bureau of Naval Weapons Program.

Boston—March 14

"Relationship Between Research and Functional Organizations," Military and Industrial," Brig. Gen. B. G. Holzman, AFCRL; H. W. Leverenz, RCA.

Boston—January 17

"Some Guidance and Control Aspects of a Satellite Rendezvous Vehicle," Messrs. E. Capen, C. King, E. Wallner, Jr., RCA.

Boston—December 5

"Reliability in Our Command and Control Systems," Brig. Gen. C. H. Terhune, Jr., Electronic Systems Div., Bedford.

Boston—November 8

"Potential Physical Hazards of Microwave Radiation," Dr. R. L. Carpenter, Tufts University.

Los Angeles—April 4

"Problem Guide Release Program," A. Scarpa, Army Signal Corps.

"Technical Objective Document Release Program," USAF Systems Command.

Philadelphia—March

"Operational Characteristics of the Comlognet System," H. P. Guerber, RCA, Camden.

Tour of the RCA Camden plant activities.

Rome-Utica—April 24

Election of Officers.

Rome-Utica—April 10

"Communication by Orbiting Dipoles," Dr. R. M. Lerner, M.I.T., Lincoln Lab.

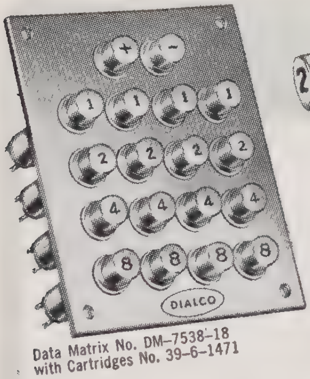
San Francisco—March 6

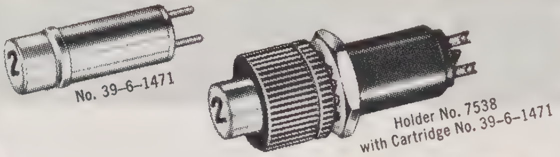
"The Satellite Control Facility and the Facility Test Center," M. Tolson, Lockheed Satellite Test Center, Sunnyvale, Calif.

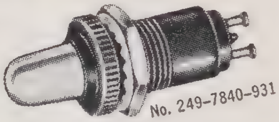
Washington, D.C.—May 16

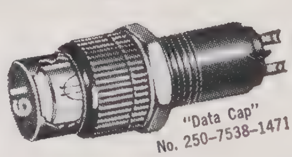
"Impact of Research and Advanced Development in Physical and Applied

(Continued on page 78A)









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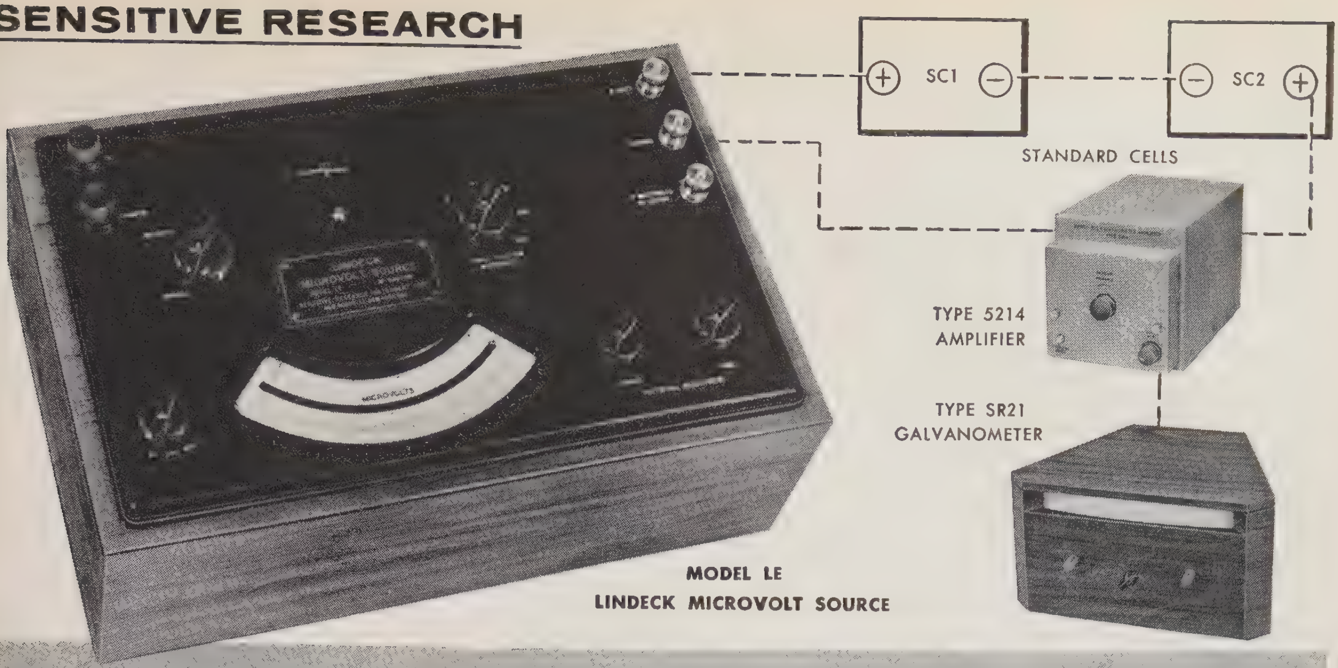

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2. The investigation of thermal emfs and other low level DC signals.

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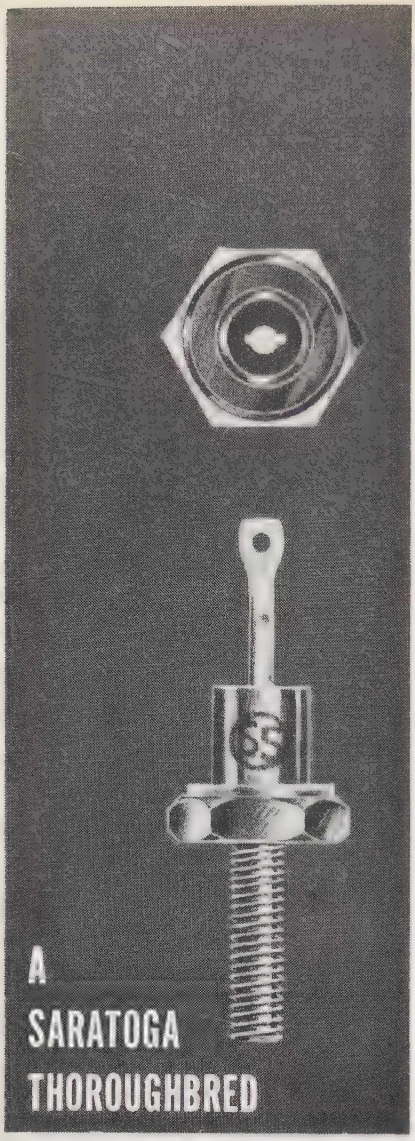

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Professional Group Meetings

(Continued from page 76A)

Mathematical Sciences," Dr. A. Shostak, Office of Naval Research, Washington, D. C.

NUCLEAR SCIENCE

Albuquerque-Los Alamos—February 20

"Nondestructive Testing," G. H. Tenney and P. D. Edwards, Los Alamos Scientific Lab.

Los Angeles—April 17

"Radioactive Decontamination," P. Parisean, Tuco Products, Wilmington, Calif.

Washington, D. C.—April 4

"New Techniques for the Measurement of Cosmic Ray Charge Spectrum and the Conduction of Positron Experiments," Dr. G. H. Ludwig, Goddard Space Flight Center.

Washington, D. C.—January 31

"The Technical Aspects of Health Physics," L. A. Garcia, Naval Res. Lab., Washington, D. C.

PRODUCT ENGINEERING AND PRODUCTION

Philadelphia—March 14

"Joint Formation Technology," Dr. L. Pessel, RCA, Camden.

"Case Study in Welded Packaging," R. M. Steigerwald, Sippican Corp., Marion, Mass.

San Francisco—March 20

"Testing Versus the State of the Art," E. B. Edberg, Varian Associates, Inc.

Other activities: Plant tour of microwave tube product and test areas, the environmental lab. and the standards lab. followed the talk.

RADIO FREQUENCY INTERFERENCE

Chicago—April 10

"Radiated Interference Measurements at Microwave Frequencies." R. Friedman, Polarad Electronics Corp., Long Island City.

Chicago—February 13

"Instrumentation for RFI Measurements," M. Hargess, Empire Devices Corp., Amsterdam, N. Y.

Chicago—December 12

"Aspects and Limitations of the Present Military Specs on RFI," R. J. Gianni, Teletype Corp., Chicago; J. C. Klouda, Elite Electronics, Chicago.

Los Angeles—March 15

"Electromagnetic Interference and the RFI Engineer's Responsibilities," G. Burkhardt and H. Schultz, Hughes Aircraft Co.

"Initiating an Electromagnetic Interference Control Program, W. Lash, Douglas Aircraft Co.

Philadelphia—April 17

"The RAD-HAZ Program: Radiation Hazard to Materiel," J. Hinds, U. S. Naval Air Development Center, Johnsville, Pa.

Washington, D. C.—May 8

"Electronic Weapons System Compatability," R. K. Hothem, Welex Electronics, Washington, D. C.

Washington, D. C.—March 20

"EIA Moves to Simplify RFI Specifications," D. C. Ports, Jansky and Bailey.

RELIABILITY AND QUALITY CONTROL

Boston—May 11

"Potential Application of Reliability Techniques in Communications Production Lines," R. M. Jacobs, Sylvania, Waltham.

"How Failure Indicators can Improve Reliability," W. Bishop, A. F. Cambridge Center.

Other Activities: Film—"AGREE IN ACTION," G. W. Lindsey, Wright-Patterson A.F.B.

Boston—April 5

"Designing Circuits to Meet Reliability Goals," A. M. Okuna, RCA, Somerville, N. J.

"Operating Characteristic Curves for Reliability Measurement," A. J. Bonis, General Motors, Milwaukee.

Chicago—March 9

"Use of Reliability Program in Military Contract Bidding," R. E. Crimmel, AC Spark Plug Co., Milwaukee.

Los Angeles—March 19

"Talks and Plant Tour" (Burroughs Corp. Electro Data Div., Pasadena) R. W. Anderson, H. Livingston, L. Bewley, and H. P. Schluter, Burroughs.

Philadelphia—April 18

"Significance of Large Life Testing Programs, R. A O'Brien, Corning Glass Works, Bradford, Pa.

Philadelphia—March 13

Human Reliability Under Stress," Dr. A. Siegel, Applied Psychological Services, Wayne, Pa.

San Francisco—March 21

"Reliability Models for Complex Ground Systems," K. M. Hall, Sylvania, Mountain View, Calif.

San Francisco—February 21

"Automation to Eliminate Human Effects on Reliability," L. J. Paddison, Sandia Corp., Albuquerque, N. Mex.

Washington, D. C.—May 10

General Business meeting and election of officers.

Washington, D. C.—April 10

"The Impact of Reliability on the Engineering Profession," Dr. Leslie W. Ball, Boeing Co., Seattle, Wash.

Space Electronics and Telemetry

Los Angeles—March 20

"A Planetary Landing and Observation Package," A. T. Owens, Hughes Aircraft, Culver City.

"The Concept of Adaptive Bandwidth Compression," D. R. Weber, Packard Bell, Santa Monica.

Los Angeles—February 20

"Frequency Planning and Control for Space and Missile Telemetry," Maj. W. E. Birks, USAF.

"Factors Determining Permissible RFI Limitations in the National Ranges," T. M. Barrett, Pacific Missile Range, Pt. Mugu, Calif.

Orlando—May 9

"PCM Telemetry Techniques," L. C. Watson, Texas Instruments, Inc.

Orlando—April 25

"Historical Review of Redstone, Jupiter, Juno II and Saturn Telemetry System Developments," W. O. Frost, NASA /MSFC, Huntsville, Ala.

San Francisco—April 17

"A Traveling Wave Amplifier and Power Supply for a Space Vehicle Telemetry Transmitter," Dr. L. A. Roberts, Watkins-Johnson, Palo Alto, Calif.

San Francisco—March 20

"PACM Telemetry," W. F. Link, Aeronutronic, Newport Beach, Calif.

Washington, D. C.—March 27

"Reducing a Mountain of Data to a Mole Hill of Information," C. M. Stout, Goddard Space Flight Center, Greenbelt, Md.

Vehicular Communications

Chicago—March 21

"C.P.D. Communications Center Field Trips," C. K. Mitter, Chicago Police Dept.

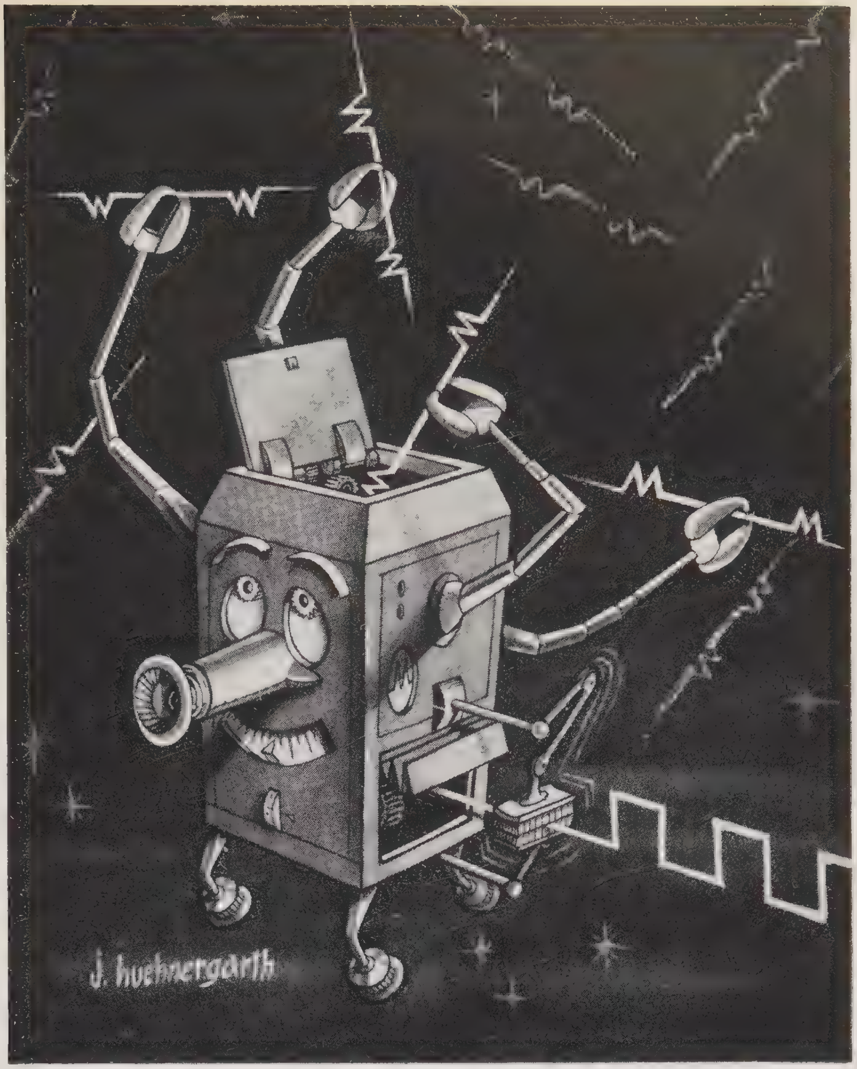
Chicago—March 9

"Chicago Police Dept. Communications System," C. K. Miller, Chicago Police Dept.

Los Angeles—April 19

"Building Reliability into Communications Equipment," J. McAdam, Internatl. Electronic Research Corp., Burbank, Calif.

(Continued on page 80A)



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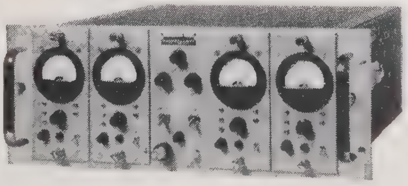

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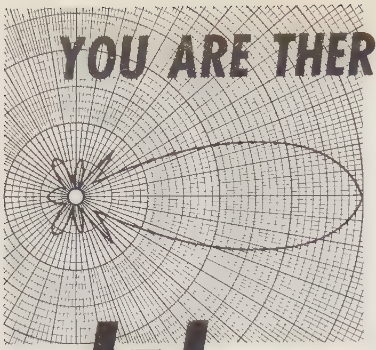
Output Impedance......75 ohms
Stability...Eight hours continuous without readjustment

Vitro ELECTRONICS



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Professional Group Meetings

(Continued from page 79A)

Los Angeles—March 15

"New Developments in the Radio Common Carrier Industry," R. C. Crabb, Mobilfore, Inc., Los Angeles.

"Tape Recording of Talk Given at the PGVC National Convention," R. Galvin.

Section Meetings

Alamogordo-Holloman

"AAAS Science Fair Program"; 4/19/62.

"High Speed Magnetic Tape Recording Techniques," J. Braet, Ampex Corp.; 5/15/62.

Albuquerque-Los Alamos

Student Paper Competition; 4/25/62.

Atlanta

"Detection of Intelligent Signals From Space," J. A. Webb, Lockheed-Georgia Co.; 4/27/62.

Beaumont-Port Arthur

"I Spent One Year In Algeria," J. T. Neff, Methodist Church; Election of Officers; 5/8/62.

Benelux

"Computer Installation," A. Nouell, IBM France; 2/12/62.

Binghamton

"Perceptrons and Artificial Intelligence," F. Rosenblott, Cornell University; 4/9/62.

Boston

"Science in Government," E. Fubini, Dept. of Defense; "Report on Merger," R. L. McFarlan, Past IRE President; 3/11/62.

Canaveral

Business Meeting; 4/19/62.

Cedar Rapids

"How to Build a Brain," J. Steele, Wright-Patterson AFB; 4/25/62.

Chicago

"The Phonetic Typewriter," Dr. Olson, RCA Laboratories; 5/11/62.

China Lake

"Electrical Relationships in Optics," H. E. Bennett, USNOTS; 4/26/62.

"Automatic Data Processing in the Internal Revenue Service," R. B. Johnson, IBM; 5/15/62.

Cleveland

"World-Wide Communications Via Satellite Relays in Space," H. S. Black, Bell Telephone Labs.; Joint meeting with AIEE, ISA and ASME; 1/11/62.

"Transistorized Portable T.V. Camera," J. W. Alinsky, Thompson Ramo Wooldridge Corp.; 2/8/62.

"R.F. Power Measurements and Couplers," W. H. Jaeger and Staff, Bird Electronic Corp; 3/8/62.

"Information Storage Density of Magnetic Recording and Other Systems," M. Camras, Armour Research Foundation; 4/12/62.

Colombia

"Propagation of Electromagnetic Waves," A. Ochoa S., Colombian Navy, 3/6/62.

"Hall Effect," W. Wesphatl, Universidad Javeriana—Bogota; 3/23/62.

"Plans for the Development Communications in Colombia," A. Ospina, Colombian Navy; 4/13/62.

Dallas

"Vistas In Radio Astronomy," F. D. Drake, National Radio Astronomy Observatory; 4/24/62,

Egypt

"The Image Orthicon Camera," F. Ibrahim, U.A.R. Broadcasting & TV; 10/11/61.

"Electronic Circuit Requirements for Kinescope Recording," F. Salleh, UAR Broadcasting & TV; 12/27/61.

Elmira-Corning

"Color Perception and Reproduction," C. S. McCamp, National Bureau of Standards; 2/19/62.

"Medical Electronics," C. Berkley, Rockefeller Institute; 3/12/62.

Emporium

"Instant Heating Tubes," E. G. Dorgelo, Amperex Electronics; 4/17/62.

Evansville-Owensboro

"Linear Amplifiers," W. B. Bruene, Collins Radio; 4/11/62.

"The Electronics Industry—Its Growth and Problems," L. B. Davis, General Electric Co.; Annual Banquet; 5/16/62.

(Continued on page 86A)

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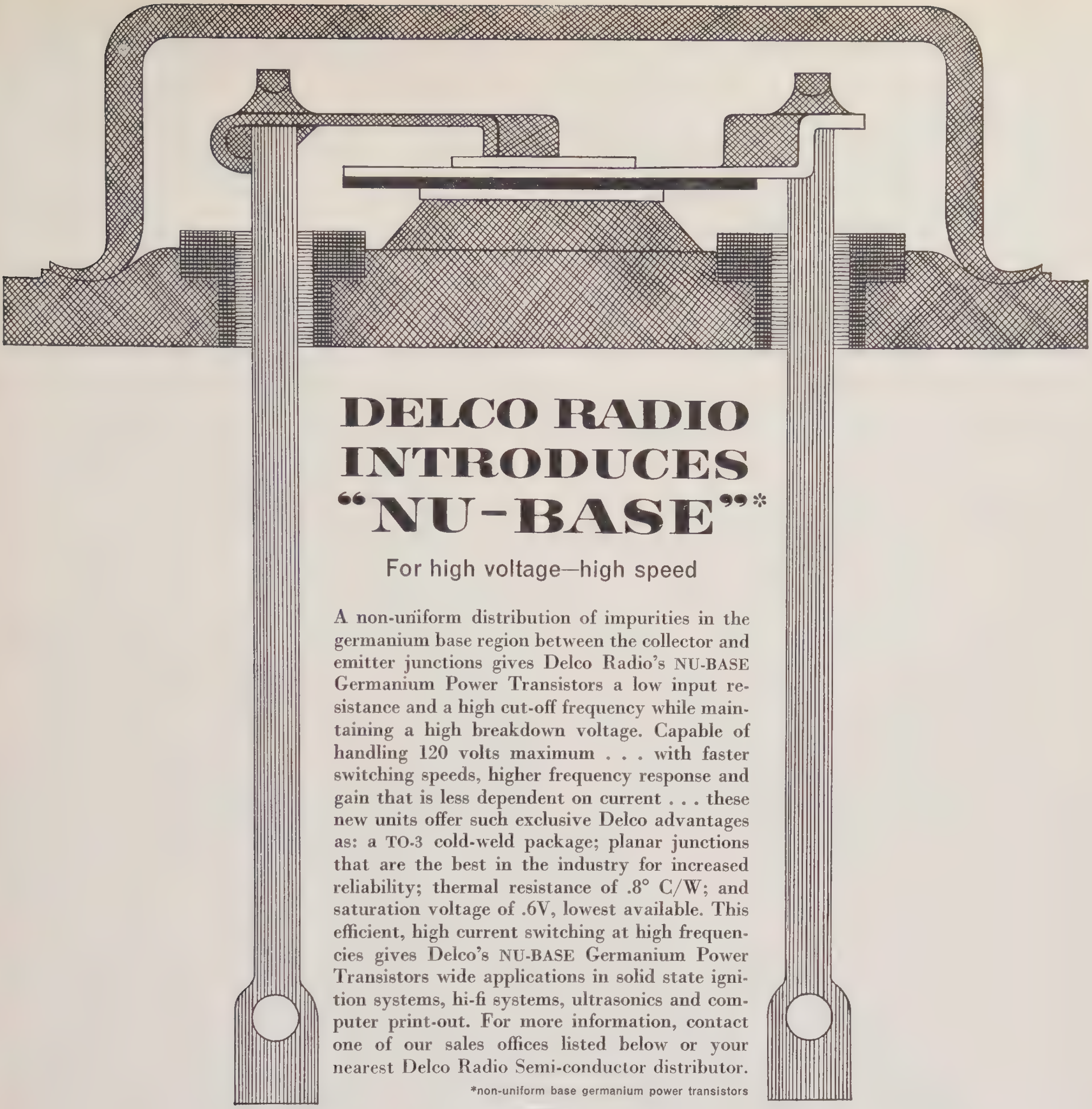

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TYPE	Vcbo	Vcer*	Vce**	hfe Ic @ 5A	Icbo @ 85°C	Tj
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2N1073A	80V	80V	0.6	20-60	10MA @ 60V	110°C
2N1073B	120V	120V	0.6	20-60	10MA @ 100V	110°C

*Reb=100Ω **Ic=5A, Ib=0.5A

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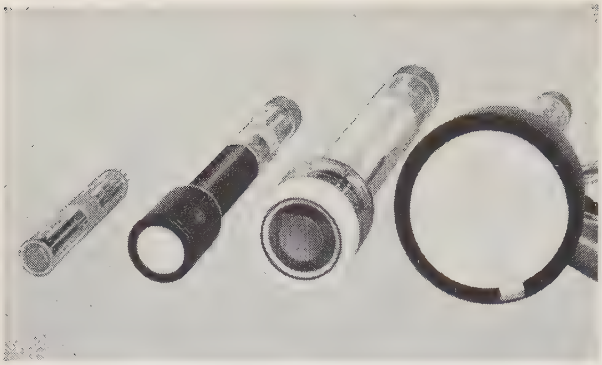

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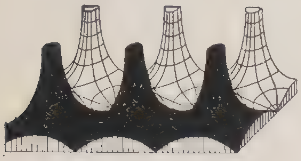
Proceedings of the IRE

Poles and Zeros



Lists of Standards. The policy on the publication of lists of current standards has been revised. Complete lists of current standards are to be published once per year and lists of additions and deletions are to be published monthly. All lists are to be within three months of up to date as of the date of publication. To assure accuracy and to minimize time delay, the Standards Committee Chairman is designated as Editor of the IRE List of Current Standards. The date of publication will appear in the heading of the list as an aid to those who strip the page from the PROCEEDINGS for reference use.

As a result of the new policy the IRE List of Current Standards should become more authoritative and useful to the membership.

Changing Patterns. As a trend, U. S. engineering students are showing increasing interest in advanced degrees in engineering. The data table in June "Poles and Zeros" showed that the number of Master's degrees has almost doubled in the last seven years, and the number of Ph.D.'s has increased by 50 per cent (which represents an essentially unchanged percentage of B.S. degrees granted—these have increased 50 per cent during this period but are now showing a monotonical decline). Several colleagues in engineering education agree that the motivational and intellectual potentials of present day student bodies are such that, in the limit, higher degrees in engineering could be earned in the ratios of one Ph.D. per three M.S. per ten B.S. degrees. For convenience these ratios are expressed in this editorial as Ph.D./M.S./B.S. = 1/3/10.

Several messages can be gleaned from Table I which presents the numbers of each degree awarded in several of the major engineering fields in 1961. The Ph.D./M.S./B.S. ratios of 0.6/2.3/10 in the case of chemical engineering most nearly approximate the 1/3/10 engineering saturation ratios. The high interest in graduate degrees evidenced here very probably is the result of the close relationship of chemical engineering to chemistry which has a long tradition of graduate study and research (note that the chemistry ratios, 4.6/4.4/10, are far above the "saturation ratios" stated for engineering). The mechanical engineering ratios of 0.14/1.8/10 seem to indicate less interest and emphasis in advanced study than that prevalent in the other fields listed. Aeronautical engineering and civil engineering ratios are listed to give the reader perspective in studying the data on electrical engineering, which is, of course, of special interest.

The electrical engineering ratios of 0.26/2.4/10 indicate that Ph.D. proportional output can be increased by about four to one. The M.S. output, however, is very near saturation—only about 25 per cent further increase is possible under present M.S. degree standards. There is little question among educators that the output at both advanced degree levels will move nearly to saturation within the next decade and possibly within five years. The implications to industry of this trend are greater than are generally realized. For example, industrial recruiters on university campuses are consistently shocked at their very low yield of high-grade average students. The probability of hiring young engineers who have outstanding potential and who hold only the B.S. degree is approaching zero. The principal exceptions are those industries who, because of locations or special relationships with universities, provide on-the-job opportunities to pursue advanced degrees. The present day relative unavailability of exceptional B.S. degree engineers is in strong contrast to the situation extant prior to this decade.

Many industries have stated consistently that they have no need for advanced degree holders. In the present climate these industries may be in serious danger of becoming unable to compete in engineering because the stated degree policy virtually shuts them off from a majority source of the most highly motivated and most capable staff members. Once our universities approach closely the saturation level for higher degrees, a company which wishes to have an engineering staff which is clearly above average must employ in the ratios 1 Ph.D./2 M.S./7 B.S. This assumes that each holder of a higher degree holds also all lower degrees—thus the degree conferring ratios 1/3/10 becomes 1/(3−1)/(10−3) or 1/2/7. It is admittedly true that an "above average" staff might be assembled out of outstanding B.S. men, including outstanding men with less-than-outstanding grade records, but the present day market for engineers is such that few can achieve this improbable result.

The most important point is this: the largest fraction of the engineering and industrial leaders of the future will be men who are obtaining higher degrees. Perhaps this result will accrue as much from the inherent quality of the men involved as from the impact of graduate education, but, whatever the cause, advanced degrees are taking on new significance in our profession.

TABLE I
(derived from data in 1962 ASEE yearbook)

Engineering Field	Number of Degrees awarded			Ratios Ph.D./M.S./B.S.
	Ph.D.	M.S.	B.S.	
Aeronautical	42	416	1225	0.34/3.4/10
Chemical	171	641	2822	0.6/2.3/10
Civil	171	1199	5043	0.23/2.2/10
Electrical	250	2327	9569	0.26/2.4/10
Mechanical	106	1341	7626	0.14/1.8/10

Fifty-Year Hams. This year marks the fiftieth anniversary of amateur radio licensing by the U. S. Government. All hams are reminded that those who can prove they were licensed in 1912 and who are still active today are eligible for awards at a golden anniversary banquet on October 13 in New York City, provided that they submit proof before August 15 to John Huntoon, ARRL, West Hartford, Conn. For further details see page 14A of the April PROCEEDINGS.—T.F.J.

W. B. Bruene

Director, 1962–1963

Warren B. Bruene (A'45–M'45–SM'49–F'61) was born in Beaman, Iowa, on November 1, 1916. He received the B.S. degree in electrical engineering from Iowa State University in 1938.

His entire radio engineering career has been spent with the Collins Radio Company, Cedar Rapids, Iowa, which he joined in 1939. Here he served as Design and Development Engineer and then as Project Engineer on numerous amateur high-frequency communication and shortwave broadcast transmitters. In 1951 he participated in an extensive single-sideband study and investigation. The techniques developed in this program served to make SSB practical for general HF communication use and gave it the impetus needed for general adoption by the radio communication industry. In 1953 he became Engineering Group Head responsible for the design and development of SSB and ionospheric scatter transmitters. In 1958 he became Division Technical Consultant and in 1960 was appointed Assistant Director to that division. In 1961 he was appointed to the position of Senior Technical Consultant.

Mr. Bruene has been a frequent contributor to the trade and technical journals. He contributed the chapter on Radio Transmitters to the current edition of Henney's *Radio Engineering Handbook* and has also presented numerous papers before Section, Professional, and Student groups. He has been granted 10 patents.

His activities with the IRE began in 1945, when he became a charter member of the Cedar Rapids Section. He served as Secretary of this section in 1956, as Vice Chairman in 1957, and as Chairman in 1958. Since 1954 he has been on the IRE 15.5 SSB Transmitter Subcommittee. In 1961 he was conferred the Grade of Fellow for advancing SSB radio communications. He is currently on the National Fellow Awards Committee for a two-year period.

Scanning the Issue

The Fundamental Noise Limit of Linear Amplifiers (Heffner, p. 1604)—If one were to look back over the electronics landscape of the last few years and map its chief topographical features, surely the area of low noise devices would be clearly discernible as one of the major pinnacles of progress. The maser, which introduced radically new and important concepts, and the parametric amplifier, with its simplicity and utility, stand as twin peaks which have dominated much of the technical literature output of this period. At the same time, the rapid evolution of other new fields, particularly radio astronomy and space electronics, has given great emphasis to the importance of developing extremely sensitive receiving systems. A fundamental question underlying this work is whether it is theoretically possible to construct a perfectly noiseless amplifier. If not, what is the minimum possible noise temperature? This is a question which has been discussed by several authorities, using various approaches and terms of reference. In examining the question here, the author chooses a frame of reference (the linear, or phase-preserving amplifier) and a method of approach (Heisenberg's uncertainty principle) which lead to a simple and more rigorous analysis. Both the analysis and the results will interest all who are concerned with low noise amplification, including in particular those who tend to use coherent light for communication purposes.

Negative *L* and *C* in Solid-State Masers (Kyhl, *et al.*, p. 1608)—This paper shows the "negative resistance" of a maser material as a reactive component associated with it and discusses when and how to take it into consideration. As larger gains and bandwidths are obtained with improved maser materials and designs, this negative reactance effect becomes more apparent. Not only must it be taken account of, it also can be taken advantage of. A reactance compensation scheme has been devised which makes use of this effect to improve considerably the gain-bandwidth performance of a cavity maser. The experimental results reported here for a cavity maser operating at 9 kMc are particularly interesting in that a very wide bandwidth was achieved, a bandwidth formerly attainable only with traveling-wave masers.

Introduction to the Theory of VLF Propagation (Wait, p. 1624)—As a complement to its program of review papers, the PROCEEDINGS publishes from time to time papers of a tutorial nature. Review papers provide surveys of the current state of the art, whereas tutorial papers are intended primarily to instruct interested readers in basic principles and methods of solving engineering problems. This paper is tutorial in nature and is one of a series which was solicited for the PROCEEDINGS by the Tutorial Subcommittee of the IRE Wave Propagation Committee. In it the author discusses both the geometrical or hop theory and the waveguide mode theory of propagation of VLF radio waves. In so doing, he has expertly brought together a body of knowledge which for the most part has been developed only in the last five or six years and which forms the basis of a field which is currently important and very active.

Composite Characteristics of Negative Resistance Devices and Their Application in Digital Circuits (Renton and Rabinovici, p. 1648)—This paper deals with an area which has received considerable attention as a result of the discovery of the tunnel diode, namely, the use of two-terminal negative resistances in switching applications. The authors show how several negative resistance elements can be interconnected to produce composite voltage-current characteristics which can be very useful in various types of digital circuits. The characteristics of semiconductor negative resistance devices are normally critically dependent on the device material and geometry. This restriction, however, has been neatly avoided by means of a modified flip-flop circuit which enables the designer to tailor the composite characteristics to suit his purpose, a feature that will interest both device designers and circuit engineers.

Phase-Stable Oscillators for Space Communications, Including the Relationship Between the Phase Noise, the Spectrum, the Short-Term Stability, and the *Q* of the Oscillator (Malling, p. 1656)—Despite the fact that crystal oscillators have been with us for 40 years, relatively little has been written on the subject treated by this paper—phase instability. This has been due not to oversight but to the difficulty in observing and measuring the phenomenon. It is a phenomenon that is now becoming increasingly important in efforts to extend the range of deep-space communications by means of extremely narrow-band techniques—techniques which require extremely phase-stable oscillators. This discussion of the origin and the methods of observing and measuring oscillator phase noise therefore comes as a timely contribution.

Harmonic Generation, Rectification, and Lifetime Evaluation with the Step Recovery Diode (Krakauer, p. 1665)—"Step recovery" is the name given by the author to a particular type of diode which switches very abruptly from reverse storage conduction to cutoff, in about a nanosecond. This step recovery action can be used to generate waveforms which are very rich in high-order harmonics in the gigacycle region. The paper is concerned with the factors that go into the mating of this diode with its circuit. As a by-product of the analysis, the author derives a general expression for rectification efficiency which is applicable to any semi-conductor diode and describes a method for evaluating lifetime diode.

Frequency Sounding Techniques for HF Communications over Auroral Zone Paths (Jull, *et al.*, p. 1676)—Much effort and experience has gone into the perfection of methods for predicting optimum working frequencies for high-frequency communication circuits. These methods serve well the majority of the time. However, under disturbed propagation conditions, long-term predictions are no longer reliable and, at the same time, it is difficult to make short-term predictions promptly enough to avoid periods of loss of radio contact. This paper investigates the use of frequency sounding techniques as a means of quickly and systematically sampling a sequence of channels to determine the optimum channel at any time. Air-ground trials during geomagnetic storms show that this procedure of frequency selection can indeed result in substantial improvements in the reliability and the channel utilization efficiency of HF communication circuits.

The Fundamental Noise Limit of Linear Amplifiers*

H. HEFFNER†, FELLOW, IRE

Summary—If the uncertainty principle of quantum mechanics is applied to the process of signal measurement, two theorems relating to amplifier noise performance can be deduced. First, it can be shown that it is impossible to construct a linear noiseless amplifier. Second, if the amplifier is characterized as having additive white Gaussian noise, it can be shown that the minimum possible noise temperature of any linear amplifier is

$$T_n = \left[\ln \frac{2 - 1/G}{1 - 1/G}\right]^{-1} \frac{h\nu}{k}.$$

In the limit of high gain G this expression reduces to that previously derived for the ideal maser and parametric amplifier. It is shown that the minimum noise amplifier does not degrade the signal but rather allows the use of an inaccurate detector to make measurements on an incoming signal to the greatest accuracy consistent with the uncertainty principle.

INTRODUCTION

SINCE THE advent of the maser, there have been a number of treatments of the noise figure or noise temperature of this and other potentially low noise devices such as the parametric amplifier.[1-4] Most of these have treated each specific device as a quantum system and have determined a limiting noise temperature arising because of amplified spontaneous emission. Although the details of the calculations differ, investigations of the minimum noise temperature due to this effect yield values of the order of $h\nu/k$ for both the maser and the parametric amplifier.

The maser and the parametric amplifiers are phase preserving amplifiers, or, in the terminology employed here, linear amplifiers. They have been characterized broadly as voltage amplifiers. There is another type of amplifier which does not preserve the signal phase which can be classed as a quantum counter. Weber[2,5] has proposed two forms of such amplifiers and has pointed out that they have no spontaneous emission noise. Thus these phase-insensitive counters have a zero-limiting noise temperature. This result opens the question of whether there are possible forms of linear amplifiers—linear in the sense of phase preserving—which also have a limiting noise temperature approaching zero.

In order to settle this question one needs to look for a general physical principle which will apply to all amplifiers regardless of the details of the specific amplification process. An appropriate one is the uncertainty principle of quantum mechanics which forms one of the basic postulates of quantum theory. Although it has resulted in important limitations on the accuracy of measurements possible in atomic systems, its corresponding limitations on the accuracy of signal measurements have until recently gone unnoticed. At the 1959 Quantum Electronics Conference, Serber and Townes[6] investigated the role of the uncertainty principle in maser noise and Friedburg[7] considered its implication on the noise figure of a general amplifier. Each of these papers is open to some criticism. First, the uncertainty principle as generally interpreted is a statement about the results obtained in a physical measurement. As such it can be applied to a signal detector but not to an amplifier. An amplifier is not a measuring instrument which produces a set of data. Amplification is rather a process, a transformation of the signal. The uncertainty principle can be applied to the measurement of the results of that processing but not directly to the processing itself. A second objection to both papers concerns their lack of rigor in problems of statistical averaging, particularly in regard to the phase of a signal. Finally, in the case of Friedburg, the wrong constant was used in the statement of the uncertainty principle. As implied before, Friedburg's conclusions strictly speaking apply only to a detector, not to an amplifier, and as such do not indicate what class of amplifier falls under the uncertainty limitation, nor how this limitation is affected by the gain.

This purpose of this paper is to develop in a simple but rigorous fashion the limitations on the noise performance of linear amplifiers which are implied by the uncertainty principle. First it will be shown that there is no such thing as a noiseless linear amplifier. Next, by characterizing the amplifier as adding white noise, the minimum possible noise temperature is derived. The resulting expression when the gain is large is exactly that derived for the limiting noise performance of the maser and the parametric amplifier.

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† Stanford Electronics Laboratories, Stanford University, Calif.

[1] K. Shimoda, H. Takehashi, and C. H. Townes, "Fluctuations in amplification of quanta with application to maser amplifiers," *J. Phys. Soc. Japan*, vol. 12, pp. 686–700; June, 1957.

[2] J. Weber, "Maser noise considerations," *Phys. Rev.*, vol. 108, pp. 537–541; November, 1957.

[3] M. W. Muller, "Noise in a molecular amplifier," *Phys. Rev.*, vol. 106, pp. 8–12; April, 1957.

[4] W. H. Louisell, A. Yariv, and A. E. Siegman, "Quantum fluctuations and noise in parametric processes," *Phys. Rev.*, vol. 124, pp. 1646–1654; December, 1961.

[5] J. Weber, "Masers," *Rev. Mod. Phys.*, vol. 31, pp. 681–710; July, 1959. See also N. Bloembergen, "Solid-state infrared quantum counter," *Phys. Rev. Lett.*, vol. 2, pp. 84–85; February, 1959.

[6] R. Serber and C. H. Townes, "Amplification and Complementarity," in "Quantum Electronics," C. H. Townes, Ed.; Columbia University Press, New York, N. Y., pp. 233–255; 1960.

[7] H. Friedburg, "General amplifier noise limit," in "Quantum Electronics," C. H. Townes, Ed.; Columbia University Press, New York, N. Y., pp. 228–232; 1960.

THE UNCERTAINTY PRINCIPLE

The uncertainty principle, first formulated by Heisenberg in 1927, claims that complete accuracy is impossible to obtain in the simultaneous measurements of certain physical quantities. In its most familiar form, it asserts the fundamental inaccuracy which must result in the simultaneous measurement of a particle's momentum p and position x. If we define the uncertainty in measurement to be the rms deviation from the mean in the distribution obtained from an ensemble of measurements, then the uncertainty in the measurement of momentum Δp and the uncertainty in the measurement of position Δx are related by

$$\Delta p \Delta x \geq h/4\pi. \tag{1}$$

This relation can be interpreted in the following way. The process of measuring cannot be divorced from the physical process being measured. Not only does the act of observing affect the system being observed, but it does this in a way which cannot be precisely predicted. It is this quality of unpredictability which formed the new content of the uncertainty principle.

In its most general form, the uncertainty principle applies to measurements of any two canonically conjugate quantities[8] such as, for example, the energy of a system and the precise time at which the system possesses this energy,

$$\Delta E \Delta t \geq h/4\pi. \tag{2}$$

Still another form of the principle applies to the measurement of the number of quanta in an oscillation and its phase

$$\Delta n \Delta \phi \geq \tfrac{1}{2}. \tag{3}$$

This latter statement of the principle may be made plausible by substituting the relations $E = nh\nu$ and $\phi = 2\pi\nu t$ into the preceding equation. We shall use this last formulation of the uncertainty principle to derive two basic theorems on amplifier noise performance.

THE UNAVOIDABLE NOISINESS OF LINEAR AMPLIFIERS

The first conclusion which emerges from the uncertainty principle is: *It is impossible to construct a noiseless linear amplifier.* We can prove this statement by postulating the existence of a noiseless linear amplifier and then showing that it violates the uncertainty principle.

Suppose we have a perfect linear amplifier by which we mean the following. If during any given interval we measure the number of photons n_2 produced at the output, we find that it is related to the number of input photons n_1 by a constant G, the gain of the amplifier.

$$n_2 = G n_1. \tag{4}$$

Secondly, if we measure the phase ϕ_2 of the output, we find that it is equivalent to the input phase ϕ_1 with perhaps the inclusion of an additive phase shift θ.[9]

$$\phi_2 = \phi_1 + \theta. \tag{5}$$

Such an amplifier is linear in the sense that the phase is preserved and the output quanta are linearly related to the input quanta. It is perfect in that no noise is added. Note that frequency converters which derive their gain solely by the frequency conversion factor do not fall under this definition of a linear *amplifier* in that the photon gain G is unity.

Let us now attach to the perfect linear amplifier an ideal detector, ideal in the sense that it is capable of detecting the number n_2 of output photons and the output phase ϕ_2 within an uncertainty,

$$\Delta n_2 \Delta \phi_2 = \tfrac{1}{2}, \tag{6}$$

the minimum value allowed by the uncertainty principle. (See Fig. 1.) Thus we imagine that we make a measurement of the output photons and phase which together with the uncertainties introduced by the detector we write symbolically as $(n_2 \pm \Delta n_2)$ and $(\phi_2 \pm \Delta \phi_2)$.

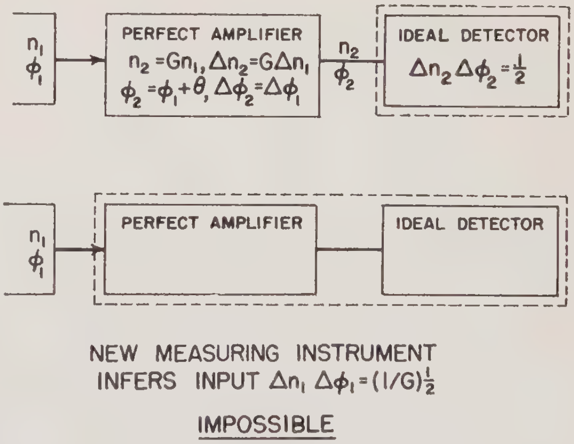
n_1
ϕ_1
PERFECT AMPLIFIER
$n_2 = Gn_1, \Delta n_2 = G\Delta n_1$
$\phi_2 = \phi_1 + \theta, \Delta\phi_2 = \Delta\phi_1$
n_2
ϕ_2
IDEAL DETECTOR
$\Delta n_2 \Delta\phi_2 = \frac{1}{2}$
n_1
ϕ_1
PERFECT AMPLIFIER
IDEAL DETECTOR
NEW MEASURING INSTRUMENT
INFERS INPUT $\Delta n_1 \Delta\phi_1 = (1/G)\frac{1}{2}$
IMPOSSIBLE

Fig. 1—Thought experiment to show the nonexistence of a perfect amplifier.

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[8] In mathematical form, the uncertainty principle states that if the operators A and B which represent physical observables a and b satisfy the commutation relation

$$AB - BA = iC,$$

then the uncertainties in the measurement of a and b satisfy the relation

$$\Delta a \Delta b = \tfrac{1}{2}\langle C \rangle,$$

where the term uncertainty stands for the root mean square deviation from expectation value, *e.g.*,

$$\Delta a = [\langle A^2 \rangle - \langle A \rangle^2]^{1/2}.$$

[9] These are operationally valid constructs since we can prepare two signal sources, one of which has an accurately known photon output and the other of which has an accurately known phase. If each of these is applied in succession to the amplifier input and if in succession two detectors are applied to the amplifier output, one of which measures number of photons without giving phase information and another which measures phase without giving photon number information, we can determine the constants of the amplifier to arbitrary precision. Such a determination can, in fact, be made with a single signal source and a single detector if a sufficiently large signal level is used since the accuracy in the determination of phase and the relative accuracy in the simultaneous determination of photon number are each proportional to $1/n^{1/2}$.

We now change our point of view and look upon the combination of perfect amplifier and ideal detector as a single measuring instrument. The measurement of $(n_2 \pm \Delta n_2)$ and $(\phi_2 \pm \Delta\phi_2)$ when referred to the input of the amplifier implies an input number of photons $(n_1 \pm \Delta n_1) = 1/G(n_2 \pm \Delta n_2)$ and an input phase $(\phi_1 \pm \Delta\phi_1) = (\phi_2 \pm \Delta\phi_2) - \theta$. Thus the uncertainty in the measurement of input photons and phase is such that

$$\Delta n_1 \Delta\phi_1 = \frac{1}{G} \cdot \frac{1}{2}. \tag{7}$$

This conclusion is clearly impossible since it violates the uncertainty principle. Therefore our postulated perfect linear amplifier cannot exist. It must add some uncertainty, that is, noise.

MINIMUM NOISE TEMPERATURE OF A LINEAR AMPLIFIER

We can pursue this argument even further to prove the following result. *The minimum noise temperature of a linear amplifier characterized by additive white Gaussian noise is*

$$T_n = \left[\ln \frac{2 - 1/G}{1 - 1/G}\right]^{-1} \frac{h\nu}{k}, \tag{8}$$

and the minimum mean square phase fluctuation is

$$\Delta\phi_a^2 = \frac{(G-1)h\nu B}{2P}. \tag{9}$$

Here h is Planck's constant, ν is the frequency, k is Boltzmann's constant, B is the bandwidth and P is the signal power.

The proof of this assertion employs the same conceptual scheme used previously, a linear amplifier (no longer considered noiseless) followed by an ideal detector. Again a measurement is made by the detector of the output phase ϕ_2 and photon number n_2. This measurement will include as before the same uncertainties introduced by the detection process but will also include the uncertainties which we have seen must be added by the amplifier. Let us label the uncertainties introduced by the detector Δn_d and $\Delta\phi_d$ and those added by the amplifier Δn_a and $\Delta\phi_a$. If we assume the processes which give rise to these two sets of uncertainties are uncorrelated, then the total uncertainties as actually measured, Δn_2 and $\Delta\phi_2$, can be obtained from

$$\Delta n_2^2 = \Delta n_a^2 + \Delta n_d^2$$
$$\Delta\phi_2^2 = \Delta\phi_a^2 + \Delta\phi_d^2. \tag{10}$$

These equations merely assert that the variances of two uncorrelated random processes add.

Let us again shift our point of view and look upon the combination of amplifier and detector as a single measuring instrument. The measured uncertainties Δn_2, $\Delta\phi_2$ now imply an uncertainty in the measurement of the input phase and photon number given by

$$\Delta n_1^2 = \frac{1}{G^2}(\Delta n_a^2 + \Delta n_d^2)$$
$$\Delta\phi_1^2 = \Delta\phi_a^2 + \Delta\phi_d^2. \tag{11}$$

Our proof proceeds by first demanding that the inferred input uncertainties be the least allowed by the uncertainty principle, *i.e.*, $\Delta n_1 \Delta\phi_1 = \frac{1}{2}$. This condition insures that the amplifier uncertainty is the smallest possible. We then characterize this amplifier uncertainty by white Gaussian noise and determine the noise temperature corresponding to this minimum uncertainty.

First, however, we must make sure that the detector is matched to the amplifier, for although the product of the uncertainties $\Delta n_d \Delta\phi_d$ is set, their ratio is not. We can assure the best detection performance by minimizing the product $\Delta n_1 \Delta\phi_1$ given by (11) with respect to the ratio $(\Delta n_d/\Delta\phi_d)$ while still demanding that

$$\Delta n_d \Delta\phi_d = \tfrac{1}{2}. \tag{12}$$

This process results in the relation

$$\frac{\Delta n_d}{\Delta\phi_d} = \frac{\Delta n_a}{\Delta\phi_a} \tag{13}$$

which simply states that the minimum over-all uncertainty comes about when the detector measures number and phase with the same relative uncertainties as those introduced by the amplifier.

We must make sure that the detector is matched to the amplifier in another sense. Let us assume that the amplifier has a bandwidth B. This characteristic implies that the detector should sample the output at intervals of $\tau = \frac{1}{2}B$. If the interval is made longer, the full information transmission capabilities of the amplifier are not being used, while if it is shorter, not only are some of the data redundant, but also, because of the fluctuations in the output, the uncertainties are greater than necessary. Thus the matching of the detector to the amplifier implies two things, first that the ratios of the uncertainties are made equal and second that the time interval over which the number of output photons and the phase are detected is one half of the reciprocal bandwidth.

Let us now multiply (11) together, introduce the conditions of (12) and (13), and demand that the uncertainty in the measurements referred to the input be the minimum allowed by the uncertainty principle, that is

$$\Delta n_1 \Delta\phi_1 = \tfrac{1}{2}. \tag{14}$$

The resulting equation is

$$\frac{G^2 - 1}{4} = \Delta n_a^2 \Delta\phi_a^2 + \Delta n_a \Delta\phi_a. \tag{15}$$

If we put this equation in the form

$$\left(\frac{\Delta\phi_a}{\Delta n_a}\right)^2 \Delta n_a^4 + \left(\frac{\Delta\phi_a}{\Delta n_a}\right) \Delta n_a^2 - \left(\frac{G^2 - 1}{4}\right) = 0 \tag{16}$$

we can solve for Δn_a^2 in terms of the ratio $(\Delta n_a/\Delta\phi_a)$ to give

$$\Delta n_a^2 = \frac{G-1}{2}\left(\frac{\Delta n_a}{\Delta\phi_a}\right). \tag{17}$$

Little more can be done unless we specify the nature of the amplifier uncertainty. Let us characterize the uncertainty as additive white noise. The statistical properties of a signal contaminated by white Gaussian noise have been extensively studied.[10] One result is that the probability density function for the output phase approaches a Gaussian distribution for large SNR's and has a variance given by

$$\Delta\phi_a^2 = \frac{\Delta P}{2P}. \tag{18}$$

Here ΔP is the noise power and P is the signal power. For large SNR's the variance in the power distribution is given by

$$\Delta P^2 = 2P\Delta P \tag{19}$$

so that (18) becomes

$$\Delta\phi_a^2 = \frac{\Delta P^2}{4P^2}. \tag{20}$$

Since the integration time of the amplifier is $\tau=\frac{1}{2}B$, (20) can be put in terms of the variance of the number of photons Δn_a^2 detected during this interval

$$\frac{\Delta n_a}{\Delta\phi_a} = \frac{2P\tau}{h\nu}. \tag{21}$$

This result inserted in (17) together with the relation

$$\Delta n_a^2 = \frac{\Delta P^2\tau^2}{(h\nu)^2} = \frac{2P\Delta P\tau^2}{(h\nu)^2} \tag{22}$$

gives for the minimum noise power introduced in the output of the amplifier

$$\Delta P = (G-1)h\nu B. \tag{23}$$

The effective noise temperature T_n is obtained by dividing by the amplifier gain to refer the noise power to the input and then determining what temperature is required for a black body to radiate the same power. That is, we must find the value T_n for which

$$\frac{h\nu B}{e^{h\nu/kT_n}-1} = \left(1-\frac{1}{G}\right)h\nu B. \tag{24}$$

The result is

$$T_n = \left[\ln\frac{2-1/G}{1-1/G}\right]^{-1}\frac{h\nu}{k}. \tag{8}$$

According to (19) and (23), the minimum mean square phase fluctuations are

$$\Delta\phi_a^2 = \frac{(G-1)h\nu B}{2P}. \tag{9}$$

These last two equations give relations for the best possible noise performance of any linear amplifier whose uncertainty is characterized by white Gaussian noise. It is interesting to note that in the limit of high gain, the minimum noise temperature becomes

$$T_n = \frac{1}{\ln 2}\frac{h\nu}{k}, \tag{25}$$

which is precisely the value obtained for the minimum noise temperature of the maser and the parametric amplifier derived from detailed consideration of the amplification mechanisms in the two cases. Thus we can say that both the maser and the parametric amplifier represent ideal amplifiers in so far as their ultimate noise performance is concerned.

We should also remark in passing, (8) and (9) indicate that the parametric up-converter which has power gain by virtue of the change in frequency but has unity photon gain ($G=1$), possesses a limiting noise temperature and phase uncertainty of zero. This result is in agreement with the detailed calculations of Louisell, Yariv and Siegman.[4] This sort of amplifier which does not multiply the *number* of photons, however, does not improve the capability of detecting a signal. The accuracy of the detection process at the output of the up-converter is no better than if it were performed at the input. The change in photon frequency and hence energy is immaterial since the limiting detector uncertainty is dependent solely on the number of photons arriving, not upon their energy.

THE IMPLICATIONS OF THE MINIMUM NOISE LIMIT

At conventional communications frequencies, the minimum noise temperature given by (8) is entirely negligible. At optical frequencies though, it can amount to several tens of thousands of degrees. Such a number is misleading, however, for it implies that the insertion of even the best amplifier has seriously degraded our ability to detect a signal. We can show that such is not the case by recasting the results of the previous section in slightly different form. Eqs. (22) and (23) can be combined to give the uncertainty produced by the amplifier in the number of photons as

$$\Delta n_a^2 = (G-1)n_a, \tag{26}$$

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[10] S. O. Rice, "Mathematical analysis of random noise," *Bell Sys. Tech. J.*, vol. 23, pp. 282–332, January, 1944; vol. 24, pp. 46–156, January, 1945; "Statistical properties of a sine-wave plus random noise," *Bell Sys. Tech. J.*, vol. 27, pp. 109–157, January, 1948.

and (9) can be rewritten in the form

$$\Delta\phi_a{}^2 = \frac{(G-1)}{4n_a} \tag{27}$$

to give the uncertainty in phase produced by the amplifier. If we refer these quantities to the input we have

$$\Delta n_{ai}{}^2 = \frac{1}{G^2}\,\Delta n_a{}^2 = (1 - 1/G)n_1 \tag{28}$$

and

$$\Delta\phi_a{}^2 = \frac{(1 - 1/G)}{4n_1}\,. \tag{29}$$

From (26) and (27) we see that if the amplifier gain is high, the output uncertainties introduced by the amplifier are considerably larger than those of even a poor matched detector. In this case, the total uncertainty Δn_1 in the inferred measurement of the input photon number and $\Delta\phi_1$ in the inferred measurement of input phase are closely given by (28) and (29), which relate to the amplifier alone. In the limit of high gain, the product of these uncertainties is

$$\Delta n_1 \Delta\phi_1 \cong \Delta n_{ai} \Delta\phi_a \cong \tfrac{1}{2}. \tag{30}$$

This is, of course, the minimum value allowed by the uncertainty principle. Thus the minimum noise amplifier allows us to use a poor detector, one which introduces uncertainties considerably larger than the minimum necessary, and still measure an incoming signal with an accuracy approaching the best allowed by the uncertainty principle. There still remains a question of what limitation is put on the rate of information transmission by this maximum allowable accuracy of detection. The answer to this question, however, must await the development of a quantum theory of communication.

Negative *L* and *C* in Solid-State Masers*

R. L. KYHL†, MEMBER, IRE, R. A. McFARLANE‡, MEMBER, IRE, AND M. W. P. STRANDBERG§, FELLOW, IRE

Summary—**The analysis of solid-state cavity masers is extended to include the reactive component of the paramagnetic resonance. This reactance is inverted (in opposition to Foster's reactance theorem). A two-cavity network makes use of this negative frequency dependence of reactance to obtain a broad-band flat-topped amplifier response. In verification of this theory a ruby maser has been built which has a 95-Mc bandwidth at 14-db gain and operates at 9000 Mc and 1.5°K. This performance is comparable to that of published, tapered magnetic field traveling-wave masers. General network limitations on cavity maser amplifiers are derived. Broadbanding techniques that have been published for parametric amplifiers are essentially equivalent. The tuning of the broad-band amplifier is critical. The same performance can be achieved in a unilateral transmission maser by using circularly polarized cavities, but the problem of circuit design and tuning with the increased number of parameters has thus far prevented successful operation.**

I. INTRODUCTION

THE STIMULATED emission behavior of the active material in a solid-state maser can be characterized satisfactorily by its contribution to the complex electric or magnetic susceptibility of the material. (Beam masers are somewhat more complicated in this respect.) Typically this susceptibility shows a sharp resonance at a frequency corresponding to the quantum transition involved. The imaginary component of the susceptibility is, of course, responsible for the maser gain, but the real, or reactive, component must also be present. In narrow-band systems this reactance may be masked by the larger reactive effects of the microwave cavity or circuits. As larger gains and bandwidths are obtained with better substances and design configurations, the reactive component must be taken into consideration to obtain a correct analysis of the circuit behavior. When the population distribution between the quantum levels is inverted to achieve maser amplification, both components of the susceptibility reverse sign. The resulting frequency dependence of reactance corresponds to the situation that would obtain in conventional circuit analysis if the symbols

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L and C could be assigned negative values.[1]

This report describes the construction and successful operation of one scheme for utilizing the negative L and C properties of inverted populations to achieve improved gain-bandwidth performance from a cavity maser. We call this "reactance compensation." Other efforts in this direction have been reported.[2] The same combination of negative R, L, and C appears in parametric amplifiers, although for entirely different reasons.[3]

This analysis will be entirely classical, although quantum phenomena are important in determining the susceptibilities that we take as our point of departure.

Large-signal nonlinearities may be safely ignored at the signal levels for which masers are useful. Saturation effects at the signal frequency are adequately treated by permitting slow time variation of the susceptibility.

The pumping mechanism by which the inverted population is achieved does not enter the discussion, although it should be recognized that the circuit performance will be affected by failure to achieve inversion over the entire volume of the active material.

II. Basic Theory

We introduce a simplified model for detailed calculations. A resonant cavity containing a substance showing quantum-mechanical resonance absorption can be well represented near resonance by the equivalent circuit of Fig. 1. The series circuit represents the cavity resonance (including any nonresonant susceptibilities of the material), and the parallel circuit represents the resonance susceptibility of the material. There are several approximations and pitfalls in this model. The cavity must, of course, have a single isolated high-Q resonance. The representation of the quantum-mechanical resonance by a single degree of freedom needs justification, since there are, in fact, at least 10^{14} active ions all resonating near the frequency range that is of interest. Some of the subtleties of this view are discussed in Appendix I and a more complete discussion is presented elsewhere.[4] The resulting simplification in Fig. 1 can be used to represent a Lorentz-shaped line. In many cases of interest the observed line shape is more nearly Gaussian, with the resulting reduction of absorption or emission (but not reactance) in the wings of the line. Notwithstanding these criticisms, it is felt to be best to analyze the simplest possible circuit that exhibits the phenomena in which we are interested.

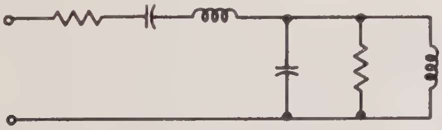

Fig. 1—Equivalent circuit for cavity containing resonant susceptibility.

Other simple choices of circuit could have been made with a suitable shift in reference plane, including the dual of Fig. 1.[4] The present choice fits well intuitively with the use of a paramagnetic crystal such as ruby for which the permeability near resonance (Lorentzian line shape) is given by

$$\mu = \mu_0\left[1 - \frac{j\chi_{\max}''}{1 + jT_2\Delta\omega}\right] \tag{1}$$

where $\chi_{\max}''$ is the peak value of the absorptive component of the magnetic resonant susceptibility. The full linewidth is $2/T_2$, and $\Delta\omega$ represents the deviation from center frequency.

This equation "describes" the parallel circuit and part of the series inductance of Fig. 1. The remainder of the series inductance is to be associated with RF magnetic fields in parts of the cavity that do not contain active material. Alternatively, one could define an effective susceptibility $\chi_{\text{eff}}'' = f\chi_{\max}''$, where f is a filling factor. The circuit model presents an open circuit far from cavity resonance. We might have preferred a short circuit, but our choice will be shown to be convenient later. As is customary for microwave circuits, the impedance level is left arbitrary.

We now introduce an inverted-population, stimulated-emission situation by suitable "pumping" of the active material. We then have

$$\mu = \mu_0\left[1 + \frac{j\chi_{\max}''}{1 + jT_2\Delta\omega}\right] \tag{2}$$

and the equivalent circuit of Fig. 2. The $-L$ and $-C$ in Fig. 2 express the fact that the dependence of reactance on frequency is the reverse of the usual case. These results derive from the solution of the equation of motion for the quantum-mechanical system in question. In the case of paramagnetic resonance, the Bloch equations[5] show that, for every solution for the macroscopic magnetization vector, there is another solution in the same applied fields with the direction of magnetization reversed. This indicates an inverted population distribution among the magnetic sublevels, and also a reversal of both in-phase and out-of-phase magnetic currents. Bloch's analysis provides additional insight into the result that could have been obtained by substituting a negative population difference in the susceptibility formula.[6] Feynman[7] has shown that the Bloch analysis can be extended to other quantum-mechanical transitions by replacing the magnetization vector with a state vector in an abstract space. If the discussion is confined to linear systems, the same result can be obtained from the general relations between real and imaginary parts of a complex response function.[8]

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[1] R. L. Kyhl, "Negative L and C in solid-state masers," Proc. IRE (*Correspondence*), vol. 48, p. 1157, June, 1960; *Errata*, vol. 49, p. 519, February, 1961.

[2] J. J. Cook, L. G. Cross, M. E. Bair, and R. W. Terhune, "Low-noise X-band radiometer using maser," Proc. IRE, vol. 49, pp. 768–778; April 1961. See also Goodwin and Moss.[17]

[3] H. Seidel and G. F. Herrmann, "Circuit aspects of parametric amplifiers," 1959 IRE WESCON Convention Record, pt. 2, pp. 83–91.

G. L. Matthaei, "Study of optimum wide-band parametric amplifiers and up-converters," IRE Trans. on Microwave Theory and Techniques, vol. MTT-9, pp. 23–38; January, 1961.

A. G. Little, "Wide-band single-diode parametric amplifier using filter techniques," Proc. IRE, vol. 49, pp. 821–822; April, 1961.

G. Schaffner and F. Voorhaar, "A nondegenerate S-band parametric amplifier with wide bandwidth," Proc. IRE, vol. 49, pp. 824–825; April, 1961.

M. Gilden and G. L. Matthaei, "A nearly optimum wide-band degenerate parametric amplifier," Proc. IRE, vol. 49, pp. 833–834; April, 1961.

[4] R. L. Kyhl (paper being prepared for publication).

[5] F. Block, "Nuclear induction," *Phys. Rev.*, vol. 70, pp. 460–474; October 1 and 15, 1946. See Section III.

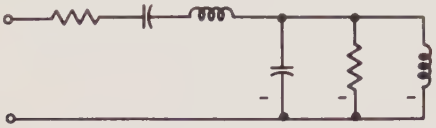


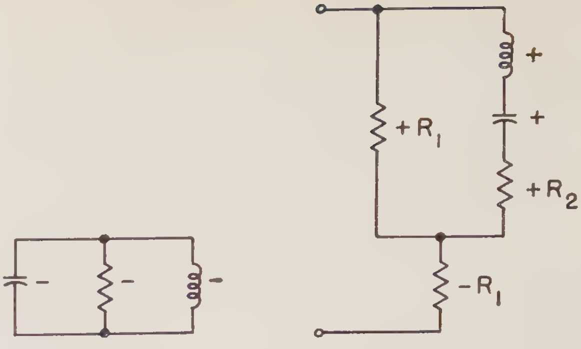
Fig. 2—Equivalent circuit for cavity containing inverted resonant susceptibility.

III. Elementary Properties of $-L$ and $-C$

The use of the negative L and C notation does not require any modification of the fundamental circuit equations. Interpretation requires a little care. For example, a resonant circuit composed of $+L$, $+C$, and $-R$ is unstable; but the combination of $-L$, $-C$, and $-R$ is stable. It becomes unstable with heavy loading, that is, with tight coupling to a resonant circuit.

Perhaps the most peculiar formal property of negative L and C circuits is negative stored energy. There is no real paradox because the devices that exhibit this property have additional stored energy that is available for maser amplification, and the total energy in the system remains positive. Total storage of energy in a network is associated with frequency dependence of reactance. By combining elements with negative stored energy and elements with positive stored energy one might hope to obtain improved frequency response.

It is not really necessary to introduce these new symbols. The circuit of Fig. 3(a) is equivalent to the circuit of Fig. 3(b) which has only negative R. However, since the negative R of the maser is found only in conjunction with the negative L and C, it is felt that the introduction of additional concepts is justified.



(a) (b)

Fig. 3—Negative R synthesis of negative L and C.

IV. Reactance Compensation

If the series impedance in Fig. 2 is very low, the circuit of Fig. 4 suggests itself. Here, except for the series circuit, cancellation of the reactance as well as greatly increased bandwidth can be achieved. The equivalent circuit of Fig. 4 corresponds physically to two cascaded cavities with resonant permeability in the second cavity, as shown in Fig. 5. For use as a maser the circuit of Fig. 5 would be used with a circulator as in conventional cavity masers. Section VIII of this report presents experimental results from a circuit of this type. Ignoring cavity losses we calculated the theoretical voltage gain curves shown in Figs. 6–8. In Section V general network theory is extended to this stituation.

From the circuit of Fig. 4 (but with cavity losses omitted) synchronously tuned at ω_0, we have near resonance

$$\begin{aligned} Y_1 &\cong 2j(\omega - \omega_0)C_1 \\ Z_2 &\cong 2j(\omega - \omega_0)L_2 \\ Y_3 &\cong -G_3 - 2j(\omega - \omega_0)C_3. \end{aligned} \tag{3}$$

Here the symbols G_3 and C_3 are taken to be positive numbers. It is preferable to express the equivalent circuit in terms of measurable quantities. By elementary circuit analysis we derive the midband voltage gain

$$\mathcal{G}^{1/2} = \frac{G_3Z_0 + 1}{G_3Z_0 - 1} \tag{4}$$

in terms of the characteristic impedance of the transmission line. The various coupling coefficients are involved. For $G_3Z_0 < 1$, the circuit is unstable. The paramagnetic (full) linewidth between half-power points is given by

$$\Delta\omega_{\text{para}} = G_3/C_3. \tag{5}$$

The magnetic Q, defined, as is customary, in terms of stored energy in the cavity fields and power dissipated by the paramagnetic material, is given by

$$Q_M = -\omega_0L_2G_3. \tag{6}$$

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[6] A. M. Clogston, "Susceptibility of the three-level maser," *J. Phys. Chem. Solids*, vol. 4, pp. 271–277; 1958.

[7] R. P. Feynman, F. L. Vernon, Jr., and R. W. Hellwarth, "Geometric representation of the Schrödinger equation for solving maser problems," *J. Appl. Phys.*, vol. 28, pp. 49–52; January, 1957.

[8] J. R. Macdonald and M. K. Brachman, "Linear-system integral transform relations," *Rev. Mod. Phys.*, vol. 28, pp. 393–422; October, 1956.

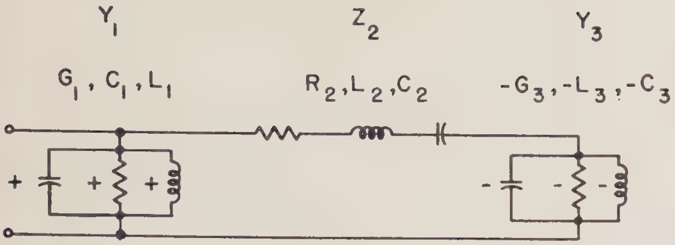

Fig. 4—Two-cavity reactance-compensation circuit.

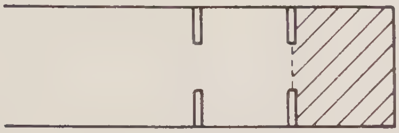

Fig. 5—Two-cavity reactance-compensation configuration.

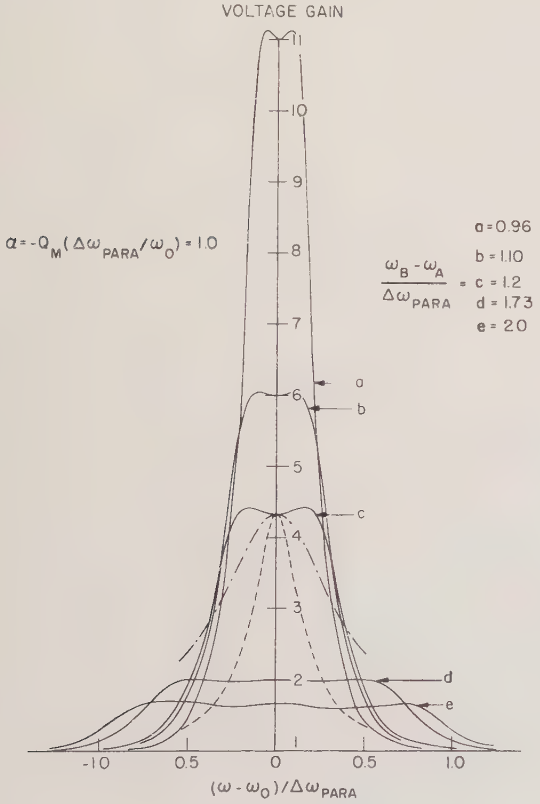

Fig. 6—Theoretical voltage gain-bandwidth curve, $\alpha = 1.0$. Curve *c* can be compared with dot-dash curve: single cavity with infinite-bandwidth ruby; and with dashed curve: single cavity with actual ruby.

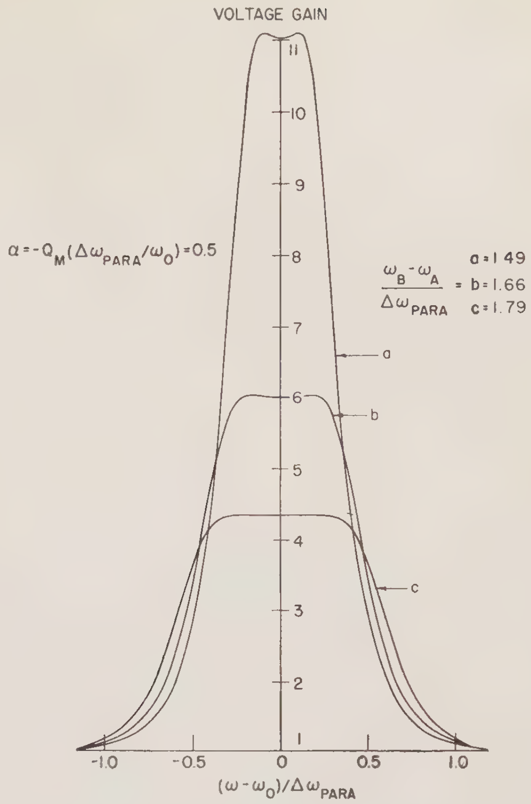

Fig. 7—Theoretical voltage gain-bandwidth curve, $\alpha = 0.5$

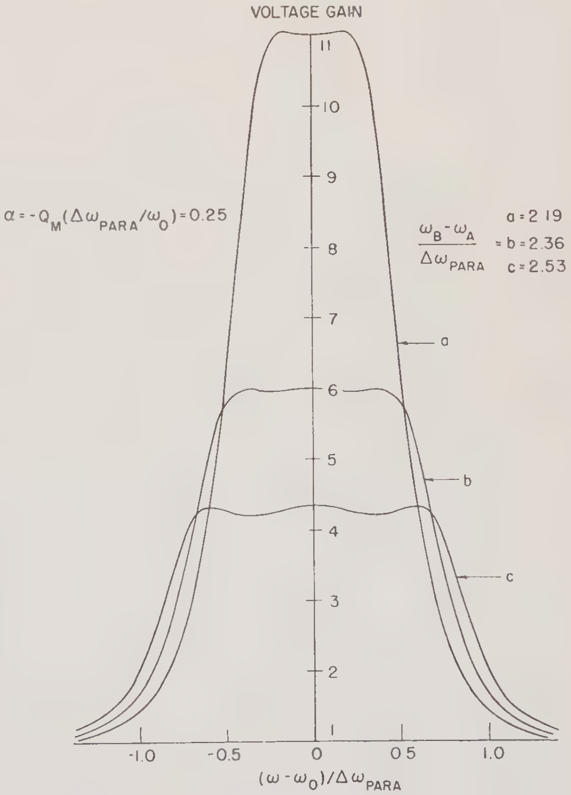

Fig. 8—Theoretical voltage gain-bandwidth curve, $\alpha = 0.25$.

Historically this definition was introduced when paramagnetic reactance was negligible compared with cavity reactance. For amplification we take Q_M to be negative. In terms of the resonance susceptibility we find that

$$Q_M = -\frac{1}{|\chi_{\max}''|} \tag{7}$$

for unity filling factor. In general the equality holds if $\chi_{\max}''$ is the effective susceptibility, which includes a filling factor.

The coupling between the two cavities produces a split in resonant frequencies in the absence of paramagnetic resonance.

$$\omega_B - \omega_A = \frac{1}{\sqrt{C_1 L_2}} \cdot \tag{8}$$

If we normalize this splitting by comparing it with the paramagnetic linewidth, we obtain a circuit coupling parameter that is given by

$$\left(\frac{\omega_B - \omega_A}{\Delta\omega_{\text{para}}}\right) = \frac{C_3}{G_3\sqrt{L_2 C_1}} \cdot \tag{9}$$

Finally we calculate the ratio of the electromagnetic energy storage at resonance in the filled cavity to the energy storage in the equivalent circuit that represents the paramagnetic resonance. This ratio is called α. It is an indication of the possibility of significant reactance compensation. We shall see that α should be as small as possible.

$$\alpha = \frac{L_2 G_3^2}{C_3} = -Q_M\left(\frac{\Delta\omega_{\text{para}}}{\omega_0}\right) = +\frac{\Delta\omega_{\text{para}}}{\chi_{\max}''\omega_0} \cdot \tag{10}$$

In terms of $\mathcal{G}^{1/2}$, α, and $(\omega_B - \omega_A)/\Delta\omega_{\text{para}}$, the equivalent circuit may be recharacterized, as shown in Fig. 9. In this figure

$$Y_1 = \frac{j}{\alpha Z_0}\left(\frac{\Delta\omega_{\text{para}}}{\omega_B - \omega_A}\right)^2\left(\frac{\omega - \omega_0}{\frac{1}{2}\Delta\omega_{\text{para}}}\right)$$

$$Z_2 = j\alpha Z_0\left(\frac{\omega - \omega_0}{\frac{1}{2}\Delta\omega_{\text{para}}}\right) \tag{11}$$

$$Y_3 = -\frac{1}{Z_0}\left[1 + j\left(\frac{\omega - \omega_0}{\frac{1}{2}\Delta\omega_{\text{para}}}\right)\right] \tag{12}$$

and the turns ratio n of the ideal transformer is such that $Z_{aa} = n^2 Z_{bb}$, with

$$n^2 = \left(\frac{\mathcal{G}^{1/2} - 1}{\mathcal{G}^{1/2} + 1}\right) \cdot \tag{13}$$

Numerical calculations were made for values of α in the range achievable with pink ruby completely filling the cavity and operating at 9 kMc at 4.2°K and 1.5°K. For each choice of gain the cavity splitting was chosen to optimize the flatness of the top of the band-pass curve. Results are shown in Figs. 6–8. Fig. 10 shows the result of detuning the magnetic field. In practice a 1-gauss shift of the magnetic field makes a significant change in band shape.

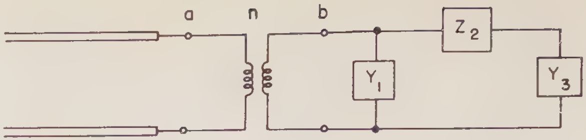

Fig. 9—Modified two-cavity reactance-compensation circuit.

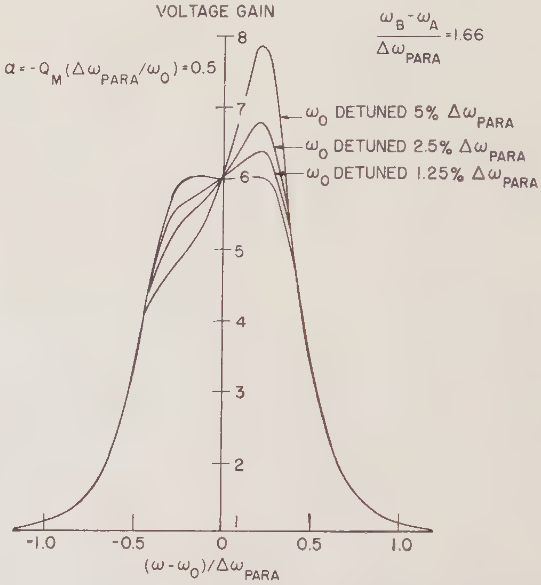

Fig. 10—Change of voltage-gain curve with detuning of resonance susceptibility.

V. General Network Theorems

Consider Fig. 11, the generalization of the circuit of Fig. 4, in which an arbitrary network is used to adjust the gain curve of the maser cavity.

The gain will be represented by the reflection coefficient, Γ, at the terminals. Because G is negative, $|\Gamma| \geq 1$. The corresponding low-pass problem with positive G was solved by Fano.[9] Our development will closely parallel his analysis. The simpler problem shown in Fig. 12 was analyzed by Bode[10] who gave the familiar relation for the low-pass network

$$\frac{1}{\pi}\int_0^\infty \ln\frac{1}{|\Gamma|}\, d\omega \leq \frac{G}{C} \cdot \tag{14}$$

The equality holds when Γ has no zeros in the right half-plane.

The low-pass equivalent of Fig. 11 is shown in Fig. 13. There are two general relationships in this case. As

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[9] R. M. Fano, "Theoretical limitations on the broadband matching of arbitrary impedances," *J. Franklin Inst.*, vol. 249, pp. 57–84, January, 1950; vol. 249, pp. 139–154, February, 1950.

[10] H. W. Bode, "Network Analysis and Feedback Amplifier Design," D. Van Nostrand Company, Inc., New York, N. Y., ch. 6; 1945.

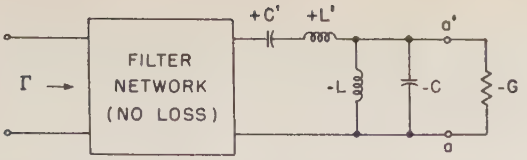

Fig. 11—Generalized reactance compensation circuit.

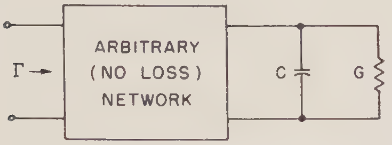

Fig. 12—Network for Bode Theorem.

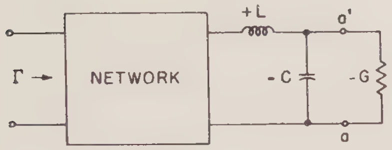

Fig. 13—Low-pass equivalent of reactance-compensation circuit.

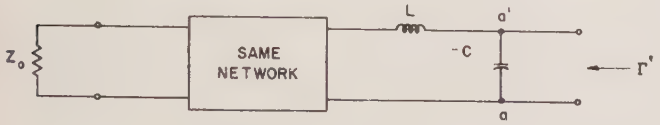

Fig. 14—Circuit for definition of Γ′.

shown in Appendix II, they are

$$\frac{1}{\pi}\int_0^\infty \ln|\Gamma|\,d\omega = -\frac{G}{C} + \sum \lambda_p - \sum \lambda_z \tag{15}$$

$$\frac{1}{\pi}\int_0^\infty \omega^2 \ln|\Gamma|\,d\omega = \frac{G^3}{3C^3} + \frac{G}{LC^2} - \frac{1}{3}\sum \lambda_p{}^3 + \frac{1}{3}\sum \lambda_z{}^3. \tag{16}$$

The λ's are defined in terms of the circuit of Fig. 14. Here, Γ′ is defined relative to $+G$, and the λ's are the values of complex $s = j\omega$ at which Γ′ has poles and zeros in the right half-plane. Relations (15) and (16) differ from the ones given by Fano in the following ways:

1) When G becomes negative the $|\Gamma|$ is inverted. Compare (14) with (15) and (16).
2) There are appropriate sign changes caused by $-C$.
3) The presence of $-C$ permits the presence of both poles and zeros of Γ′ in the right half-plane. Indeed the network is not stable without at least one pole to make the right side of (15) positive.

We now transform the expressions to the high-frequency maser case. The network is modified to shift center frequency from zero to ω_0. Then $\mathcal{G}^{1/2}$ is substituted for $|\Gamma|$. We go from a single-sided integral from zero frequency upward to an integral over the full bandwidth of the gain curve, although the limits are still 0 to ∞. This introduces a factor of 2 on the right. The L and C above (16) are *not* the same as L_2 and C_3 in (3). The correspondence must be made on the basis of $Y(\omega)$ or $Z(\omega)$. This introduces another factor of 2. For the band-pass case,

$$\frac{1}{\pi}\int_0^\infty \ln \mathcal{G}^{1/2} d\omega \cong -\Delta\omega_{\text{para}} + 2(\lambda_p - j\omega_0) \tag{17}$$

$$\frac{1}{\pi}\int_0^\infty (\omega - \omega_0)^2 \ln \mathcal{G}^{1/2} d\omega \cong \frac{2}{3}\left(\frac{\Delta\omega_{\text{para}}}{2}\right)^3 + \left(\frac{\Delta\omega_{\text{para}}}{2}\right)^2 \omega_0 \chi_{\max}'' - \frac{2}{3}(\lambda_p - j\omega_0)^3. \tag{18}$$

The expressions are now approximate because we have ignored the pass band at negative frequencies and also the negative-frequency poles, as in fact we have already done in (1) and (2). We have dropped the summations because (as is shown in Appendix III) in a properly designed maser there are no zeros—just one pole of Γ′ in the right quadrant. The network has lost some generality in the shift because the gain curve must presumably be symmetric about the center frequency ω_0 in order to correspond with the low-pass formulas. This is not a serious restriction and may not be completely necessary. The situation does not merit too close an inspection in any case, since in a practical microwave maser there are other cavity resonances and other resonant susceptibilities that are ignored here.

Eqs. (17) and (18) give the general limitations on gain and bandwidth for a single crystal, Lorentzian line-shape maser—that is, single crystal in the sense that the active material is describable by a single set of elements in an equivalent circuit. A long, thin crystal for use in a traveling-wave structure does not fit into this category. (See also Appendix I and Section IX.) It is clear from (17) that the circuit design should maximize $(\lambda_p - j\omega_0)$ for best performance; however, $(\lambda_p - j\omega_0)$ cannot be made arbitrarily large because of the restriction of (18). Since G is never less than 1 for the circuit in question, both integrals must remain positive to preserve stability. Eq. (17) gives little insight into possible gain-bandwidth figures until λ_p has been evaluated. This can be done in some particular cases. If the maser amplifier is to be a high-gain, narrow-band one, then we may set the second integral (18) equal to zero. We may then solve for λ_p and substitute in (17) so that, in the narrow-band limit, we obtain

$$\frac{1}{\pi}\int_0^\infty \ln \mathcal{G}^{1/2} d\omega = \Delta\omega_{\text{para}}\left[\left(1 + \frac{3\chi_{\max}''\omega_0}{\Delta\omega_{\text{para}}}\right)^{1/3} - 1\right] = \Delta\omega_{\text{para}}[(1 + 3/\alpha)^{1/3} - 1]. \tag{19}$$

It is seen that for poor filling factors or weak resonances $(\alpha > 3)$ the gain-bandwidth product is linear in $1/\alpha$. For strong resonance and filling factor near unity $(\alpha < 3)$ the gain-bandwidth product may become arbitrarily large, but only as the cube root of $(1/\alpha)$.

Another interesting situation is the square response with constant gain over a bandwidth of $\Delta\omega$ and unity gain outside. The integrals of (17) and (18) can be evaluated directly to give

$$\frac{\chi_{\max}''\omega_0}{\Delta\omega_{\text{para}}} = \frac{1}{\alpha} = \left(\frac{\Delta\omega}{\Delta\omega_{\text{para}}}\,\frac{\ln \mathcal{G}^{1/2}}{\pi}\right) + \left(\frac{\Delta\omega}{\Delta\omega_{\text{para}}}\,\frac{\ln \mathcal{G}^{1/2}}{\pi}\right)^2 + \frac{1}{3}\left(\frac{\Delta\omega}{\Delta\omega_{\text{para}}}\,\frac{\ln \mathcal{G}^{1/2}}{\pi}\right)^3\left[1+\left(\frac{\pi}{\ln \mathcal{G}^{1/2}}\right)^2\right]. \tag{20}$$

Although such an ideal response cannot be obtained with a finite network, (20) gives some idea of what can be accomplished with broad-band operation. For example, if we wish to achieve a voltage gain of 23, ($\ln \mathcal{G}^{1/2}=\pi$) and a bandwidth equal to a typical ruby bandwidth of 60 Mc, we need an α of 3/8 or less, which is entirely possible at low temperature.

It should be recognized that $1/\alpha$ is not a complete figure of merit for maser materials because it only tells what can be achieved relative to the natural linewidth, and, other things being equal, a broader linewidth will give broader band operation so that $\Delta\omega_{\text{para}}/\alpha$, or $(\chi_{\max}''\omega_0)$, is nearer to a true figure of merit.

VI. Verification—Experimental Determination of Optimum Ruby-Chromium Concentration

A ruby maser at 9000 Mc was built to demonstrate the operation of reactance compensation. The design was, in other respects, a conventional three-level cavity maser operated at liquid-helium temperature. One of the most important factors in achieving large gain-bandwidth operation is the choice of optimum ruby concentration. Our selection was from several boules of Linde Company synthetic ruby.

The paramagnetic linewidth of Cr^{3+} in Al_2O_3 increases with Cr^{3+} concentration, and has a residual value of approximately 42 Mc at vanishingly small concentrations.[11] As the linewidth $\Delta\nu_{\text{para}}$ is more easily measured than the density of paramagnetic centers N, it was used as an indication of the relative Cr^{3+} concentrations in the several ruby samples examined. The value of $\chi_{\max}''$ depends on $N/\Delta\nu_{\text{para}}$ for a fixed inversion ratio, and it is apparent that there should be some optimum value for N which would make $\chi_{\max}''$ as large as possible without going to unduly high concentrations in which deleterious effects, such as cross relaxation, can decrease the achievable inversion.[12]

Five samples with linewidths from 67 Mc to 220 Mc were measured. Of these only the three lowest concentration materials exhibited significant inversion when pumped. Fig. 15 shows the value of $1/|Q_M|$ which were observed at 4.2°K and 1.5°K. The 85-Mc and 106-Mc linewidth rubies were operated as single-cavity masers, and we determined the magnetic Q from gain-bandwidth measurements by using the relations [13]

$$\frac{\mathcal{G}^{1/2}B}{\Delta\nu_{\text{para}}} = \frac{2}{1+\alpha} \tag{21}$$

and

$$\alpha = \frac{|Q_M|}{\omega_0/\Delta\omega_{\text{para}}}.$$

The 67-Mc linewidth data are only approximate, as values of magnetic Q have been estimated from the measurements of the compensated amplifier performance.

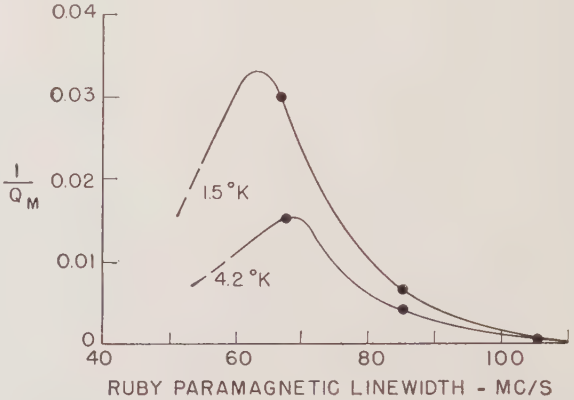

Fig. 15—Experimental ruby magnetic Q vs paramagnetic linewidth for the samples used in this work.

Clearly, the available population difference for the signal transition decreases very rapidly as the Cr^{3+} concentration is increased beyond some optimum value. The change with temperature was only a factor of approximately 2 for the lowest concentration material studied. In the absence of cross-relaxation processes this should be nearer 3. We conclude that the 67-Mc linewidth material is still slightly high in concentration, the optimum apparently being near a linewidth of 60 Mc. Unfortunately, data for samples of lower concentration were not available. In the low-concentration limit $1/Q_M$ must be proportional to concentration.

A change in line shape from Gaussian for low concentration to Lorentzian at high concentration was observed as the Cr^{3+} concentration was increased and the linewidth varied from 67 Mc to 223 Mc. (The linewidths quoted are half-power absorption full widths.)

VII. Cavity Design

The amplifier was designed to operate at a signal frequency near 9 kMc with a pump frequency of 23 kMc; operation is in the push-pull pumping mode. This required that the *c* axis of the crystal make an angle of 54.7° with the dc magnetic field.

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[11] "Research on Paramagnetic Resonances," Res. Lab. of Electronics, M.I.T., Cambridge, Mass., Eleventh Quarterly Progress Rept. on Signal Corps Contract DA36-039-sc-74895, pp. 1–3, May 15, 1960; Tenth Quarterly Progress Rept., *op. cit.*, pp. 17–27, February 15, 1960.

[12] T. H. Maiman, "Maser behavior: temperature and concentration effects," *J. Appl. Phys.*, vol. 31, pp. 222–223; January, 1960.

[13] M. W. P. Strandberg, "Unidirectional paramagnetic amplifier design," Proc. IRE, vol. 48, pp. 1307–1320; July, 1960.

To achieve the highest possible filling factor, we used the ruby crystal to entirely fill the fixed tuned microwave cavity that resonated in the TE_{101} mode at 9 kMc. It was, therefore, convenient to cut the ruby crystal as shown in Fig. 16. The H_{rf} was everywhere perpendicular to H_0, which gives strong coupling. The crystal was pumped at a higher mode cavity resonance. A number of resonances were present at 23 kMc, but it was not necessary that one of these coincide exactly with the push-pull pump frequency since saturation of both pump transitions is achievable through cross relaxation for the 67-Mc linewidth material under approximately push-pull pumping conditions. The cavity was formed by enclosing the ruby with two pieces of O.F.H.C. copper, as shown in Fig. 17, and brazing them together in a hydrogen atmosphere. The resulting block was cut down to provide a continuous 0.007–in wall of copper around the ruby, and signal and pump coupling irises were machined out.

The compensation cavity was made in a similar fashion, but contained polycrystalline sapphire (Wesgo Type A-300), a high-density, low-loss material having a dielectric constant of 10 at *X* band. The large coupling aperture to the signal waveguide lowers the resonant frequencty of this cavity approximately 10 per cent, and this must be considered in the calculation of the cavity dimensions. The size of the aperture between the cavities was adjusted with each concentration to provide for the separation of the normal-mode resonant frequencies indicated for the desired operating performance.

A movable knife-edge in front of the signal aperture in the sapphire cavity provided a very fine control of the cavity center frequency, and an adjustable capacitive post in the waveguide was used as a loading control to vary the amplifier gain. The individual cavities and the coupled system are shown in Fig. 18.

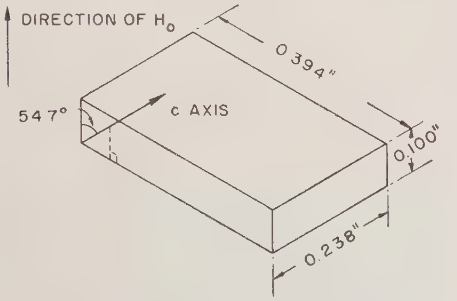


Fig. 16—Ruby crystal dimensions.

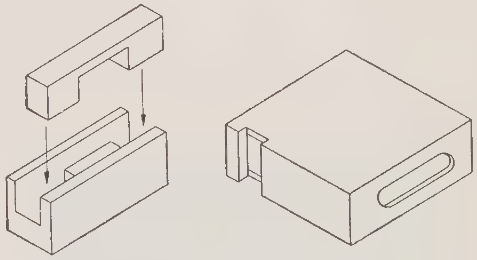


Fig. 17—Assembly procedure for copper-clad ruby cavity.

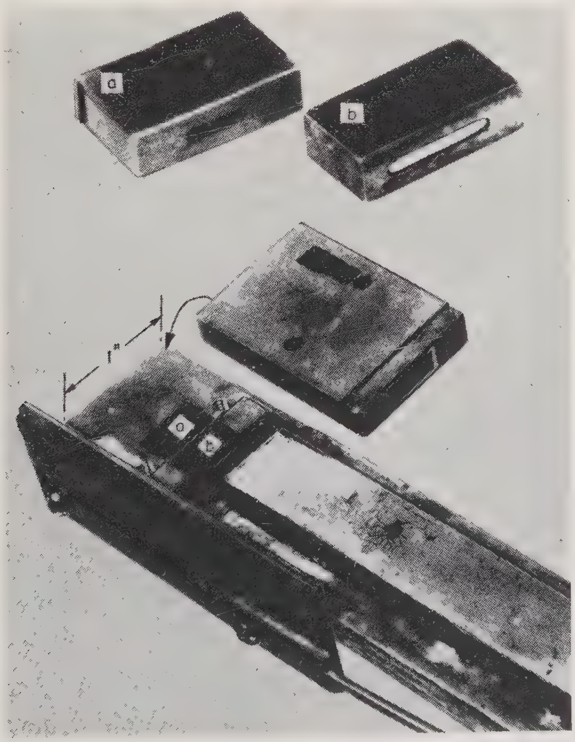


Fig. 18—Two-cavity assembly with cover block containing pump guide removed. Enlarged views of the two cavities are shown above.

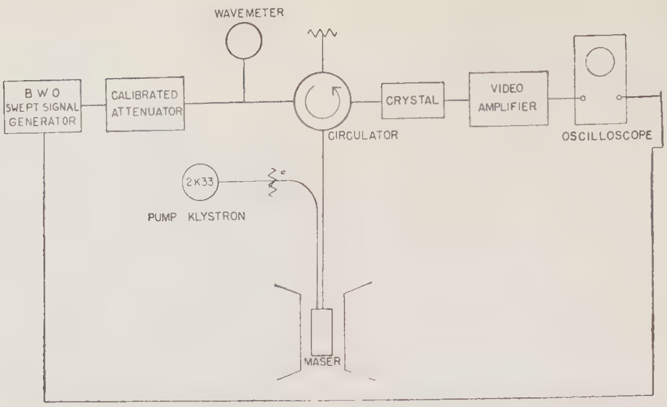


Fig. 19—Schematic drawing of test system.

TABLE I

SINGLE-CAVITY MEASUREMENTS

Paramagnetic Linewidth (mc)	Temperature (°K)	Center Frequency (mc)	$\mathcal{G}^{1/2}B$ (mc)	α	$\lvert Q_M \rvert$
85	4.2	9300	53	2.2	240
	1.5	9300	70	1.43	155
106	4.2	9100	8	24.5	2100

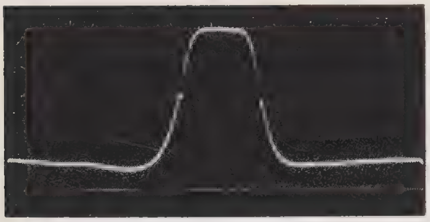


Fig. 20—Experimental power-gain curve at 4.2°K; ruby linewidth, 85 Mc; 55-mc bandwidth.

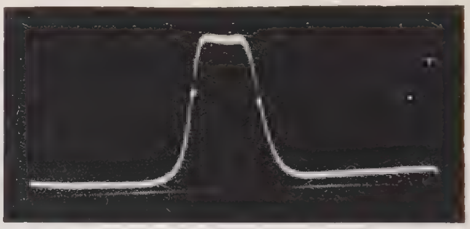


Fig. 21—Experimental power-gain curve at 1.5°K; ruby linewidth, 85 Mc; 48-mc bandwidth.

VIII. AMPLIFIER OPERATION

The test system is shown in Fig. 19. A broad-band swept oscillator was used as a signal source, and gain measurements were determined by means of a precision calibrated attenuator. To avoid amplifier saturation, we maintained output signals below −20 dbm. Sufficient video gain was available for oscilloscope presentation of the band-pass characteristics.

The pump klystron supplied 20 mw of power, and it was determined during the measurements that this was at least 3 db in excess of that required to saturate the pump transition. Significantly lower pump power was required for the low-concentration ruby.

Results

The single-cavity $\mathcal{G}^{1/2}B$ measurements made on the 85-Mc and 106-Mc materials are summarized in Table I. The values of α given in Table I for the 85-Mc linewidth material will be compared with the performance data of the same material in the compensated amplifier.

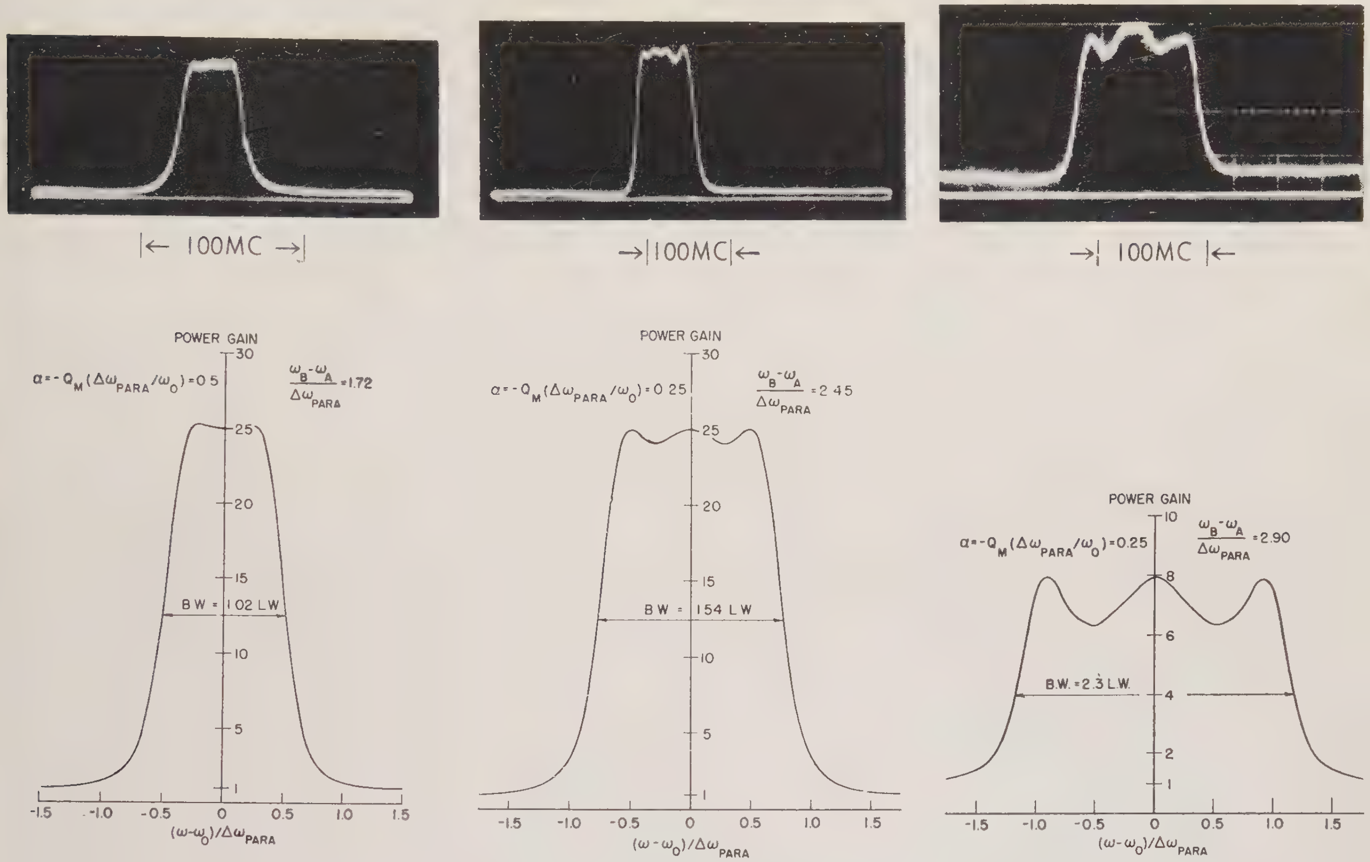
The 85-Mc linewidth ruby was operated in the double-cavity configuration at 4.2°K and 1.5°K with a circuit-coupling parameter of 1.06 which represents a separation of 90 Mc between the normal cavity modes. Fig. 20 shows the band-pass characteristic obtained at 4.2°K. Midband gain was 7.4 db, and the half-power bandwidth was 55 Mc. For a value of $\alpha = 2.2$ as determined above, the theoretical bandwidth is approximately 70 Mc at this gain. Fig. 21 shows the amplifier performance at 1.5°K. The gain was 10.6 db, and the bandwidth was 48 Mc. The theory predicts a bandwidth of 70 Mc for a value of $\alpha = 1.43$.

The results for the 67-Mc linewidth ruby are substantially better. They are summarized under a variety of design conditions at 9 kMc, in Table II. The value of α was not measured in a single-cavity maser for the 67-Mc ruby. The assumed values of α which best fit observed two-cavity operation were $\alpha = 0.5$ at 4.2°K and 0.25 at 1.5°K. The observed and theoretical band-pass curves are shown in Fig. 22 for the 9-db and 14-db gain cases. The quantity $(f_B - f_A)$/linewidth is under experimental control, but, as can be seen from Table II, the

TABLE II

Results of Measurements for 67-Mc Linewidth Ruby

Temperature (°K)	Gain (db)	Bandwidth (mc)	$f_B - f_A$ (mc)	Measured		Theoretical	
				Bandwidth / Linewidth	$f_B - f_A$ / Linewidth	Bandwidth / Linewidth	$f_B - f_A$ / Linewidth
4.2	14	50	120	0.75	1.8	1.02	1.72
1.5	14	95	155	1.4	2.3	1.54	2.45
1.5	12	108	169	1.6	2.5	—	2.58
1.5	9	122	171	1.8	2.55	2.30	2.90
1.5	~6	145	200	2.2	3.0	—	3.46



(a) (b) (c)

Fig. 22—(a) Experimental and theoretical power-gain curve for 67-Mc linewidth ruby maser. T=4.2°K; gain, 14 db. (b) Experimental and theoretical power-gain curve for 67-Mc linewidth ruby maser. T=1.5°K; gain, 14 db. (c) Experimental and theoretical power-gain curve for 67-Mc linewidth ruby maser. T=1.5°K; gain, 9 db.

value used for the calculations was not precisely the value used in the experimental measurements of bandwidth and gain.

Fig. 23 (next page) summarizes all of the measurements on the compensated amplifier and shows the necessary normal-mode splitting to achieve the flattest frequency response at a specified voltage gain, with α as a parameter. The single-cavity measurements on the 85-Mc linewidth material are substantiated here. For the 67-Mc line-width ruby at 1.5°K, the chosen value of $\alpha = 0.25$ for the theoretical calculations appears to be slightly less than that actually obtained during operation.

IX. Extension to Circularly Polarized Cavities

If the coupling of the quantum-mechanical transition to the electromagnetic field is circularly polarized, and if a cavity that can be driven in a circularly polarized mode is used, nonreciprocal gain can be achieved without the use of circulators.[14] These conditions can be partially met. With typical magnetic fields and crystal orientations as used in masers, paramagnetic resonance is elliptically polarized with the ratio between right- and left-hand circularly polarized components being

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[14] Strandberg, *op. cit.*, p. 1309.

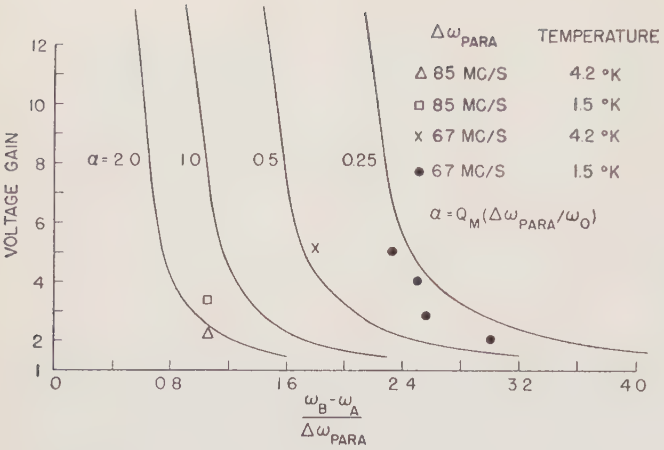

Fig. 23—Summary of experimental results and theory: voltage gain plotted against cavity coupling with ruby quality as a parameter. Optimum flatness of the top of the gain curve is assumed in the design.

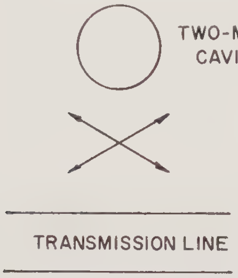

Fig. 24—Schematic drawing for production of circularly polarized resonance, with directional-coupler coupling to degenerate-mode cavity used.

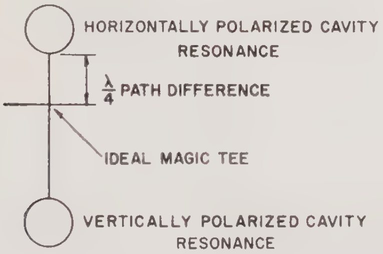
HORIZONTALLY POLARIZED CAVITY RESONANCE
$\frac{\lambda}{4}$ PATH DIFFERENCE
IDEAL MAGIC TEE
VERTICALLY POLARIZED CAVITY RESONANCE

Fig. 25—Equivalent circuit of circularly polarized resonance.

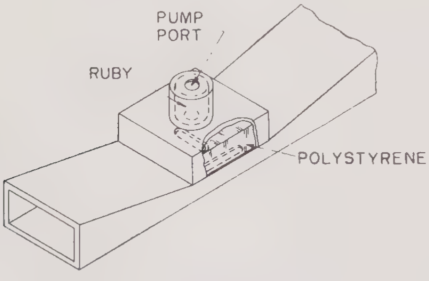

Fig. 26—Possible configuration for unilateral reactance-compensated maser stage.

strongly dependent on operating conditions.[14,15] In order to obtain circularly polarized cavity modes, it is necessary to have a cavity with two degenerate modes which is coupled, as shown in Fig. 24, by using directional-coupler coupling.[16] A useful equivalent circuit for analysis is shown in Fig. 25.

A signal in one port of the two-port circuit produces a circularly polarized mode of one sense of rotation; a signal in the other port produces the opposite sense of rotation. The resulting fields will be circularly polarized in some parts of the cavity and will more generally be elliptically polarized. Such structures can be cascaded; indeed the comb-type, unilateral, traveling-wave maser can be thought of as a cascade of a large number of individual resonators.

Reactance compensation, in principle, can be applied to unilateral cavity systems. The transmission coefficient will obey the same conditions that have been derived above for reflection coefficients in simple cavities. The effective susceptibility to be used is given by

$$\chi_{\text{eff}}'' = \frac{\int H^* \chi''(r) H d \text{ volume}}{\int H^* \cdot H d \text{ volume}}, \qquad (22)$$

where $\chi''(r)$ is a tensor. Then χ_{eff}'' will be different for the two directions of signal flow—hopefully very different. Fig. 26 shows a possible geometry. Attempts to operate such a system have not yet been successful because the large number of simultaneous circuit adjustments introduces great difficulty in practice.

X. Discussion

The experiments reported here clearly demonstrate the effect of solid-state reactances on maser performance. Agreement with theory is generally satisfactory. Numerical evaluation of $\int \ln \mathcal{G}^{1/2} d\omega$ from Fig. 21 gives 460 Mc; this value is to be compared with a value deduced from (17) and (18) and single-cavity measurements of 720 Mc. The discrepancy is undoubtedly the result of our neglect of cavity losses, although departure from the Lorentzian line shape is a factor.

A considerable increase in bandwidth has been obtained over the maximum value that is possible with a single cavity.

No noise-figure measurements were made, but the same effective noise temperature should prevail as for other maser designs. Careful construction should keep cavity losses low enough to avoid serious adverse noise contribution.

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[15] W. S. Chang and A. E. Siegman, "Characteristics of ruby for maser applications," Stanford Electronics Labs., Stanford, Calif., Tech. Rept. 156-2; September 30, 1958. (Reprinted January 30, 1959.)

[16] M. Tinkham and M. W. P. Strandberg, "The excitation of circular polarization in microwave cavities," Proc. IRE, vol. 43, pp. 734–738; June, 1955.

Some work carried out elsewhere has indicated that improved gain-bandwidth results from putting active ruby in the reactance-compensation cavity.[17] Some simple numerical calculations made here indicate the opposite when the active material in both cavities has identical resonance behavior.

It is too early to say whether reactance compensation in the form described here will be useful in maser development. A small number of cascaded, reactance-compensated, unilateral cavity units, presumably including some unilateral, reverse-attenuation elements, and possibly stagger-tuning of the paramagnetic resonance, can in principle match or exceed the performance of other designs, including traveling-wave devices. The decision as to the actual circuit to be used will be made on the basis of practical considerations. Here it must be admitted that the adjustment of reactance-compensated circuits is critical. A slight change in cavity loading will produce either a single narrow-gain curve or two sharp gain peaks, as illustrated in Fig. 27. Additional change in loading in either direction leads to instability. The traveling-wave maser that is broad-banded by means of tapered magnetic field to provide tapered paramagnetic resonance[18] frequency may well be simpler to operate. At present, solid-state reactance effects are not ordinarily taken into account in traveling-wave maser design.[20] One of the advantages of traveling-wave masers is the possibility of tuning the operating frequency by adjusting the magnetic field without the necesssity of retuning the structure. Use of reactance-compensation schemes, to achieve a flat gain-response, for example, would seriously interfere with this flexibility.

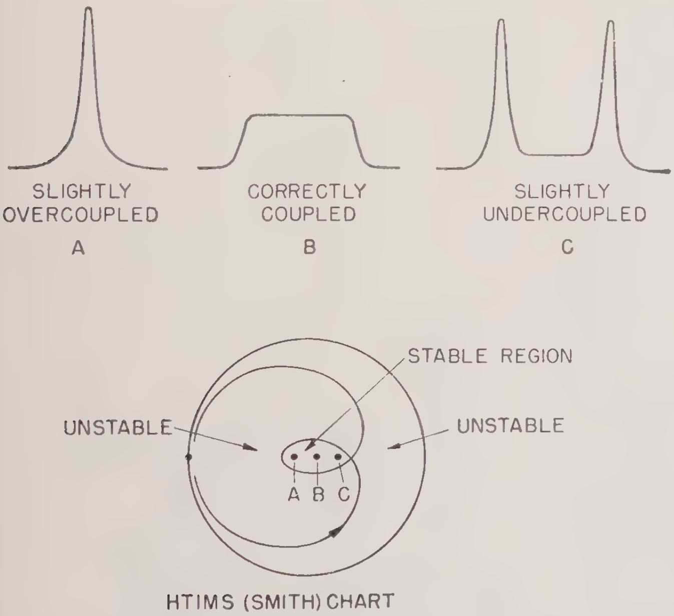

Fig. 27—Impedance behavior of reactance-compensated maser, showing effect of coupling adjustment (the HTIMS Chart is used[19]).

In any case, the inverted reactance behavior will be a factor in the analysis of any solid-state maser for which large filling factors are used.

Appendix I

Circuit Representation of Paramagnetic Resonance

The perturbation formula for initially lossless cavities[21]

$$\Delta Z = j\omega \frac{\int d \text{ volume } [H^*\Delta\mu H + \mathcal{E}^*\Delta\epsilon\mathcal{E}]}{|I|^2} \qquad (23)$$

yields the desired formula immediately. Setting

$$\Delta\mu = -\frac{j\chi_{\max}''}{1 + jT_2\Delta\omega}$$

and factoring it out of the integral, we obtain

$$\Delta Z = \omega\left(\frac{\chi_{\max}''}{1 + jT_2\Delta\omega}\right)\frac{\int d \text{ volume } H^*H}{|I|^2}\cdot \qquad (24)$$

If we combine (24) with the impedance of the cavity near resonance and assume that $\int d$ volume $H^*H/|I|^2$ is constant over the frequency range of interest (which requires use of the series resonance form for the cavity), we have an expression of the form

$$Z = R + jx(\Delta\omega) + \left(\frac{\omega\chi_{\max}''}{1 + jT_2\Delta\omega}\right)\cdot\text{constant} \qquad (25)$$

which describes the equivalent circuit of Fig. 2. This derivation, although qualitatively correct, creates difficulties. The use of a perturbation expression is valid since $\Delta\mu$ is indeed small for all maser materials that are now available. However, the constancy of $\int |H|^2 d$ volume$/|I|^2$ is open to question. The frequency range for the validity of the expression is not clear, and it is by no means obvious how to proceed in the case of more complex cavity networks. By the method of expanding the cavity fields in the set of orthonormal modes of the uncoupled cavity, several authors have shown that the admittance or impedance of an air-filled cavity can be expressed in the form[22]

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[17] F. E. Goodwin and F. W. Moss, Hughes Aircraft Co., Culver City, Calif. (private communication, November 12, 1959).

[18] S. Okwit and J. G. Smith, "Traveling-wave maser with instantaneous bandwidths in excess of 100 Mc," Proc. IRE (*Correspondence*), vol. 49, p. 1210; July, 1961.

[19] R. L. Kyhl, "Plotting impedances with negative resistance components," IRE Trans. on Microwave Theory and Techniques, vol. MTT-8, p. 377; May, 1960.

[20] R. W. DeGrasse, E. O. Schultz-DuBois, and D. Scovil, "The three-level solid state traveling-wave maser," *Bell Sys. Tech. J.*, vol. 38, pp. 305–334; March, 1959.

[21] B. Lax, "Frequency and loss characteristics of microwave ferrite devices," Proc. IRE, vol. 44, pp. 1368–1386; October, 1956. Only trivial modifications of the equations are required.

$$Y = \sum_i \frac{\text{constant}_i}{(\omega - \omega_i)} \tag{26}$$

in which the complex ω_i represents both the infinite set of complex natural resonance frequencies of the cavity with the input coupling aperture short-circuited (open-circuited in the case of the corresponding impedance formula) and also a dc term $\omega_i = 0$. The corresponding equivalent circuit is shown in Fig. 28.

For well-separated resonances it is common to truncate the circuit, lumping the reactances of all terms except one into Y_0 (as shown in Fig. 29) to obtain the simple circuit that is valid in the neighborhood of one of the resonances. If there are two closely spaced resonances in the cavity, one can similarly approximate the admittance behavior in the neighborhood of the pair of resonances by the equivalent circuit of Fig. 30(a) which, by algebraic manipulation, can be converted into the equivalent forms of Fig. 30(b)–(d). If it is possible to choose a new reference plane in an input transmission line, the circuits can be reduced to the still simpler forms of Fig. 30(e) and (f).

The extension of the general expression (26) to include other dynamic variables, such as electric or magnetic polarizations, is to be expected and is demonstrated in another paper.[4] The present problem concerns the truncation of the expression for practical analysis.

Out of the essentially infinite number of degrees of freedom introduced by the sample, how many must be retained to give an acceptably accurate equivalent circuit? For an empty cavity, all but one or two of the resonance frequencies occur outside the frequency range that is of interest. However, all of the resonances of the material itself, associated with a particular paramagnetic transition, occur in the relevant frequency interval. Clearly the overwhelming majority must represent spatial patterns of the magnetization which are very complicated and which, therefore, couple weakly, if at all, to the incident field. In order to make the problem tractable we must introduce simplifying assumptions. We have assumed that

1) The material shall be homogeneous in the sense that all portions show the same paramagnetic resonance frequency and linewidth. There is then a direct relation between the cavity-field pattern and the polarization pattern. Clearly, a radical violation of this assumption leads to chaos. We are not attempting to analyze tapered magnetic-field situations.
2) The cavity-field pattern shall be assumed not to be influenced by the material. All maser materials have small resonance susceptibilities. They are large enough to radically change network impedances, but they represent only a small perturbation on μ or ϵ. Large nonresonant susceptibilities, such as the dielectric constant of the ruby, are considered to be part of the cavity system.
3) As the final step we assert that the cavity-field patterns remain constant over the frequency range of interest, being, in fact, just the mode pattern for the particular isolated cavity resonance in question. This is a commonly made assertion but is not necessarily a good one.

Combining these three assumptions, we conclude that a single new variable is capable of describing the state of magnetic or electric polarization of the material in the frequency range of interest. If the line shape is Lorentzian, then this new variable satisfies a harmonic type of equation of motion and, when coupled with the cavity field equations, produces just one additional normal mode of the coupled system. The validity of the equivalent circuits in Fig. 30 follows directly. (The difficulty with a Gaussian line shape is that the polarization vector obeys no simple equation of motion. The case of a cavity filled completely with a uniform linear medium and having a Gaussian resonance can be solved numerically and leads to an infinite set of normal modes for each cavity mode.)

The next higher approximation is based on the fact that the fields in a cavity near resonance can be represented with considerable accuracy by a linear combination of *two* field patterns.[4] For example, these may be the field patterns for a "short" at the window and for an "open" at the window. For small- or moderate-sized coupling windows these patterns will differ primarily in the region of the window, and thus another linear combination suggests itself—one pattern being the difference between the two mentioned above and essentially the pattern of the window fringing field, the other being the ordinary mode pattern, perhaps one or the other of the modes mentioned above.

Returning to the argument for the filled cavity, we see that to match this approximation we need *two* new dynamic variables to describe the paramagnetic polarization. This is enough to describe the class of acceptable equivalent circuits. We give a physically intuitive sample in Fig. 31.

The values of the parameters in the chosen equivalent circuit can, in principle, be determined from a solution for the normal modes of the system. It is much better for the experimenter to relate the circuit parameters to the physically measurable behavior of the structure, as was done in Section IV. For this reason the choice,

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[22] J. C. Slater, "Microwave Electronics," D. Van Nostrand Company, Inc., New York, N. Y., p. 74; 1950.
K. Kurokawa, "The expansion of electromagnetic fields in cavities," IRE Trans. on Microwave Theory and Techniques, vol. MTT-6, pp. 178–187; April, 1958.

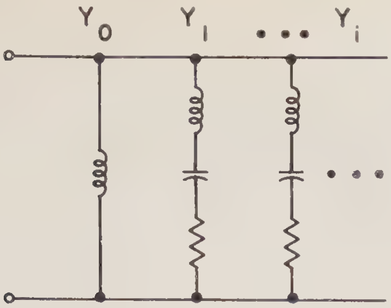


Fig. 28—Conventional equivalent circuit for normal-mode expansion of cavity impedance.

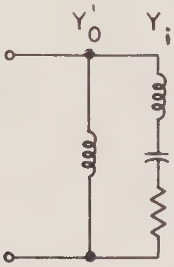
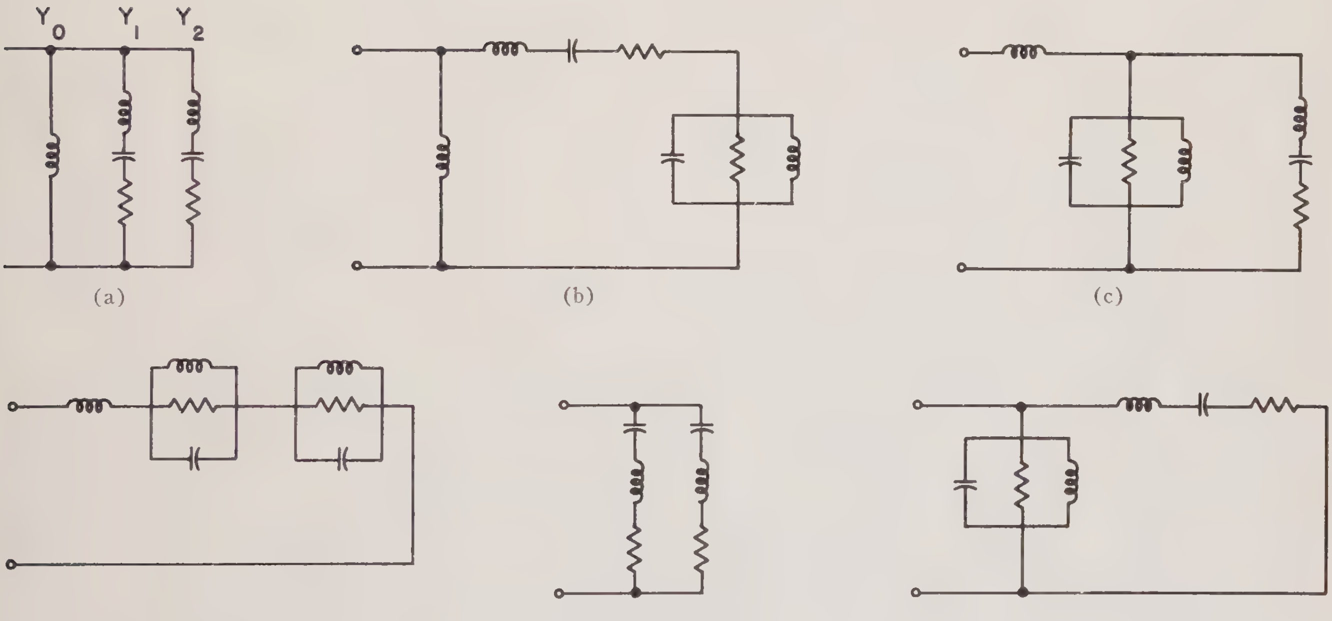


Fig. 29—Approximate circuit near an isolated resonance.



(a) (b) (c)

(d) (e) (f)

Fig. 30—Forms of approximate equivalent circuits near a pair of isolated resonances. (e) and (f) have the reference plane chosen to simplify the representation.

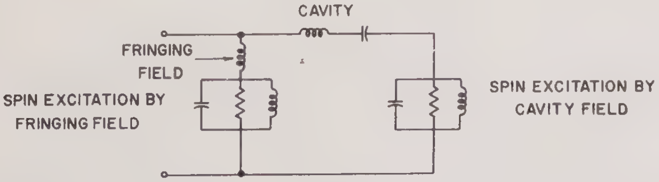

CAVITY
FRINGING FIELD
SPIN EXCITATION BY FRINGING FIELD
SPIN EXCITATION BY CAVITY FIELD

Fig. 31—Equivalent circuit for single ruby-filled cavity, including the action of the window-coupling field on the ruby resonance.

when possible, of a circuit that bears a direct similarity to the structure is extremely desirable.

Our analysis does not use the more exact circuit of Fig. 31. If we had intentionally machined out the portion of the ruby in the region of the window fringing field, the introduction of the additional circuit element would have been unnecessary. This was not done in the experiments, although it appears that it might have been a good idea.

APPENDIX II

EXTENSION OF FANO'S ANALYSIS TO THE $-L$ AND $-C$ SITUATION

We do not need to repeat the entire mathematical analysis of Fano,[9] but it is necessary to point out where changes or modifications must be made. He began his analysis by investigating the reflection coefficient Γ' (see Fig. 14). Then he argued that $|\Gamma'| = |\Gamma|$ as a corollary of the reciprocal nature of the network where Γ and Γ' are defined by the positive G equivalents of Figs. 13 and 14. The impedance levels at the two ports of the network do not influence the result directly, if it is understood that the Γ's are defined in terms of the respective conductances, $+G$ on the right and a chosen Z_0 on the left.

An essential step is a contour integration of $\ln \Gamma'(s)$ along the ω axis and around the right-half s plane at infinity. For ordinary networks $\operatorname{Re} Y \geq 0$ in the right-half s plane. Therefore, $|\Gamma'| \leq 1$ in the right-half s plane, in which Γ' can have zeros but not poles and $\ln \Gamma'$ can have logarithmic singularities wherever Γ' has zeros. It is necessary to detour the contour integral around these singularities, as shown in Fig. 32.

A typical result of this integration is given by (27). Other results can be obtained by a similar contour integration of $\omega^2 \ln \Gamma'$, $\omega^4 \ln \Gamma'$, and so on. We shall need only the second expression given in (28).

$$\int_0^\infty \ln \frac{1}{|\Gamma|}\, d\omega = \frac{\pi}{2}\left(A_1^\infty - 2 \sum_z \lambda_z\right) \tag{27}$$

$$\int_0^\infty \omega^2 \ln \frac{1}{|\Gamma|}\, d\omega = -\frac{\pi}{2}\left(A_3^\infty - \frac{2}{3} \sum_z \lambda_z^3\right). \tag{28}$$

These are Fano's equations (21) and (22).[9] The A's are coefficients in a Laurent expansion of the argument $\ln \Gamma'$ about infinity. A major point of the theory is that A_1^∞ is a function of *only* the first element of a ladder development of the entire network, starting at the right, and A_3^∞ is a function of *only* the first two elements, and so on. This is not at all obvious; the proof is given by Fano.[9] The λ's are the values of s at the logarithmic singularities in the right half-plane. There are no residues at these points, but they form branch points of a spiral-staircase nature for the logarithmic function. Successive Riemann surfaces have values of the function differing by $2\pi j$ at all points. The contribution of the detour out and back to the contour integral is therefore $2\pi j\lambda$.

We are now able to make the necessary modifications in the theory.

The argument for $|\Gamma| = |\Gamma'|$ is still valid, for reciprocity is not related to the sign of C. Changing the sign of G results in the inversion of $|\Gamma|$. The new factor in the problem is the presence of poles of Γ' in the right-half $s = j\omega$ plane. These introduce additional logarithmic singularities in the argument. Now, however, at these branch points the Reimann surfaces spiral the other way, and the contribution to the integral changes sign. Eqs. 27 and 28 become

$$\int_0^\infty \ln |\Gamma|\, d\omega = \frac{\pi}{2}\left(A_1^\infty - 2 \sum_z \lambda_z + 2 \sum_p \lambda_p\right) \tag{29}$$

$$\int_0^\infty \omega^2 \ln |\Gamma|\, d\omega = -\frac{\pi}{2}\left(A_3^\infty - \frac{2}{3} \sum_z \lambda_z^3 + \frac{2}{3} \sum_p \lambda_p^3\right). \tag{30}$$

Inserting expressions for A_1^∞ and A_3^∞ for the circuit of Fig. 13, we obtain (14) and (15).

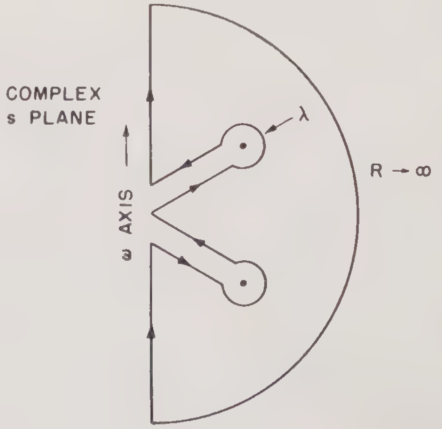


Fig. 32—Contour integral used in the derivation of the gain relations.

APPENDIX III

OPTIMUM POLE-ZERO CONFIGURATION

It can be shown that the low-pass circuit that we have been using must have just *one* pole of Γ' in the right-half s plane because the network starts with a single negative element. A plausibility argument may be made as follows: Looking in at aa' (Fig. 14) in the absence of the negative capacitance we see that Y will have a positive real part in the right half-plane and thus neither poles nor zeros. Now by adding $-sC$ to the admittance, we add a simple pole at ∞ but none in the right half-plane. However, far enough to the right in the half-plane, the real part must become arbitrarily large and negative. There must be at least one point on the positive real s-axis where $Y=-1$, and at this point there is a pole of Γ'. To show the absence of any additional poles of Γ', we consider the locus of Re $Y=-1$ in the right half-plane. This contour cannot cross the imaginary axis, and it cannot form loops or be multiply connected because there are no singularities. All that Im Y can do along this locus is behave monotonically, going to infinity at $s=\pm\infty$. Hence, there are no other points where $Y=-1$, and no other poles of Γ'.

Critics may object that this is a strange argument to make about a circuit that is only claimed to be a valid representation over a small frequency range, but the behavior of the structure should approximate the behavior of the idealized network in this frequency range.

A number of zeros of Γ' are possible, however. We should maximize $(\lambda_p-\Sigma\lambda_z)$ in (15) and keep $(\lambda_p^3-\Sigma\lambda_z^3)$ below a fixed limit in order to keep the expression in (16) positive. Now

$$[\lambda_p^3-\sum\lambda_z^3]=[\lambda_p-\sum\lambda_z]\cdot\left[\lambda_p^2+\lambda_p\left(\sum\lambda_z\right)+\left(\sum\lambda_z^2\right)+\frac{\left(\sum\lambda_z\right)^3-\sum\lambda_z^3}{\left(\lambda_p-\sum\lambda_z\right)}\right].\quad(31)$$

This expression is to be minimized while $(\lambda_p-\Sigma\lambda_z)$ is maximized, hence the last expression in brackets is to be minimized. All terms are positive—it takes a little algebra to show that $(\Sigma\lambda_2)^3-\Sigma\lambda_z^3$ is positive. Therefore, for best gain-bandwidth performance, $\Sigma\lambda_z=0$, and there are no zeros in the right half of the s plane.

ACKNOWLEDGMENT

The authors would like to express their appreciation to Dr. T. Ogawa of Doshida University, Kyoto, Japan, for his assistance with these experiments.

CORRECTION

W. Eckhardt and F. Sterzer, authors of "Microwave-Carrier Modulation-Demodulation Amplifiers and Logic Circuits," which appeared on pp. 148–162 of the February, 1962, issue of PROCEEDINGS, have called the following to the attention of the *Editor:*

1) On p. 148, table, n sec replaces Nsec.
2) On p. 153, (55), $\omega_s^2C_0^2R_{sp}$ replaces $\omega_s^2C_0^2R_{sp}^2$.
3) On p. 154, line 2, $(G_p'-G_{sp}')/G_p'$ replaces $(G_p'-G_{sp}'/G_p')$.
4) On p. 158, Table I, the last column does not belong to the MA 450/460 series.
5) On p. 161, in the line above (82), R_l replaces R_t.
6) On p. 161, (82) and (83), v_{on}, $v_{o\Sigma}$, ω, R_l replace ν_{on}, $\nu_{o\Sigma}$, w, R_z.

Introduction to the Theory of VLF Propagation*

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The following paper was solicited for the PROCEEDINGS by the Tutorial Subcommittee of the IRE Wave Propagation Committee, and appears below as a part of a continuing program of presenting review and tutorial papers on subjects of general interest and importance.—*The Editor.*

***Summary*—This paper is a self-contained exposition of the conventional theory of propagation of VLF radio waves. The model is a spherical earth surrounded by a concentric ionosphere. Although the model is highly idealized, the theory is still quite involved. The complexities arise from the long wavelengths inherent in such problems.**

In Section I the elementary geometrical or hop theory for VLF is considered. This includes a discussion of ionospheric reflection coefficients and the influence of multiple reflections. The validity of the model is established by a comparison with experimental data. In Section II, the diffractive corrections near the caustics of the ray systems are obtained. These provide a means to extend the theory to points near and beyond the horizon point for the individual hops or rays. In Section III, the waveguide mode theory is expounded. A number of approximations and simplifications are introduced in order to illustrate principles. References to more detailed analyses which use higher order approximations are given. Finally, in Section IV, the influence of a stratified ionosphere is treated by using a two-layer model.

The material in this paper was included in the Summer (1961) Lecture Course on Radio Propagation given at the Boulder Laboratories of the National Bureau of Standards, and in earlier graduate courses, at the University of Colorado.

I. THE ELEMENTARY HOP THEORY FOR VLF

A. Introduction

THE CONCEPTION that VLF radio waves propagate via multiple reflections between the earth and the ionosphere has been known for over 40 years. In spite of this simple geometrical picture, the actual calculations of the sky wave field intensities are quite involved. It is customary to simplify the analysis by assuming that the upper boundary of the ionosphere is a specular reflector which imparts a phase shift of either 0° or 180° on each reflection. This crude approximation is not justified since the ionosphere is an imperfectly-conducting medium with anisotropic properties. At VLF (less than 20 kc), Bremmer [4] has proposed that the ionosphere can be regarded as a sharply-bounded ionized medium. Using wave matching techniques, he has shown how the ionospherically reflected wave may be calculated in terms of the electron density, collision frequency, and the earth's magnetic field.

In this section, reflection coefficients are calculated in parametric form using the sharply-bounded model. These results are then compared with experimental data to obtain the most reasonable value of the parameters involved. These values are than employed to calculate amplitude and phase delays of the sky waves. Finally, the computed field strength vs distance curves for 16 kc are compared with experimental values for an all-sea path.

B. The Ionospheric Reflection Coefficients

The derivation of the reflection coefficients for a plane wave at arbitrary incidence on a plane boundary of an anisotropic homogeneous medium has been solved rigorously by Bremmer [4]. The resulting formulas are exceedingly cumbersome for purposes of computation. The same problem has also been attacked by Budden [5] who obtains somewhat more tractable results as a result of certain simplifying assumptions which are suitable for VLF. His method is employed here. In what follows, MKS units are used and the time factor exp $(i\omega t)$ is implied.

The starting point is the magnetoionic formula of Appleton and Hartree [1] for the complex refractive index μ for a homogeneous ionized medium with superimposed magnetic field. In the region from 70 to 90 km in the ionosphere where VLF are reflected, it is permissible to employ the quasi-longitudinal (Q.L.) approximation of Booker [3]. It is thus implied that the waves after they are transmitted into the ionosphere are steeply refracted toward the vertical.[1] Essentially this means that the refractive index does not depend to any great extent on the direction of propagation for temperate and polar latitudes so that

$$\mu^2 \cong 1 - i(\omega_r/\omega) \exp(\pm i\tau), \tag{1}$$

where

$$\tan \tau = \omega_L/\nu,$$

and $\omega_r = \omega_0^2(\nu^2 + \omega_L^2)^{-1/2}$. In the above, $\omega_0^2 = Ne^2/\epsilon m$, N = number of electrons per meter, e and m = charge and mass of electrons, $\epsilon=8.854\times10^{-12}$, ν=collision frequency, $\omega_L=(4\pi\times10^{-7})He/m$ and H=strength of the earth's magnetic field. In this formulation it has also been assumed that $\omega\ll\nu$.

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[1] At equatorial latitudes this Q.L. approximation can become invalid.

It is now desirable to consider four reflection coefficients ${}_{\|}R_{\|}$, ${}_{\|}R_{\perp}$, ${}_{\perp}R_{\|}$ and ${}_{\perp}R_{\perp}$ to indicate the complex ratio of a specified electric field in the wave after reflection to a specified electric field in the wave before reflection. The first subscript denotes whether the electric field in the wave is parallel ($\|$) or perpendicular ($\perp$) to the plane of incidence and the second subscript refers in the same way to the reflected wave. A Cartesian coordinate system (x, y, z) is now taken with z measured vertically upwards. The incident wave has its normal in the xz plane inclined at an angle ϕ to the z axis. The components of the electric field are $E_{\|}$ in the xz plane and $E_{\perp}$ perpendicular to this plane (*i.e.*, in the direction of increasing y). When the + sign is taken in (1), the refractive index is denoted μ_0 corresponding to the ordinary wave, and when the − sign is taken the refractive index is denoted μ_e corresponding to the extraordinary wave. With this convention, it can be shown that [3]

$$E_{\perp_0}/E_{\|_0} = -i \quad\text{and}\quad E_{\perp_e}/E_{\|_e} = i$$

in the northern hemisphere.

The incident wave is now characterized by a factor $\exp\,[-i\omega(x\sin\phi+z\cos\phi)/c]$ and the reflected wave therefore contains a factor $\exp\,[-i\omega(x\sin\phi-z\cos\phi)/c]$. Furthermore the transmitted waves have factors $\exp\,[-i\omega(x\sin\phi_0+z\cos\phi_0)\mu_0/c]$ and $\exp\,[-i\omega(x\sin\phi_e+z\cos\phi_e)\mu_e/c]$. The reflection coefficients are obtained by matching tangential field components at the air-ionosphere interface. The results, expressed in a form suitable for computation, are listed below.

$$\begin{aligned} {}_{\|}R_{\|} &= \{(\mu_0+\mu_e)(C^2-C_0C_e) \\ &\quad + (\mu_0\mu_e-1)(C_0+C_e)C\}/D \end{aligned} \tag{2a}$$

$${}_{\|}R_{\perp} = 2iC(\mu_0C_0-\mu_eC_e)/D \tag{2b}$$

$${}_{\perp}R_{\|} = 2iC(\mu_0C_e-\mu_eC_0)/D \tag{3a}$$

$$\begin{aligned} {}_{\perp}R_{\perp} &= \{(\mu_0+\mu_e)(C^2-C_0C_e) \\ &\quad - (\mu_0\mu_e-1)(C_0+C_e)C\}/D, \end{aligned} \tag{3b}$$

where

$$D = (\mu_0+\mu_e)(C^2+C_0C_e)+(\mu_0\mu_e+1)(C_0+C_e)C,$$

$$\mu_0\sin\phi_0 = \mu_e\sin\phi_e = \sin\phi, \tag{4}$$

and

$$C=\cos\phi,\qquad C_0=\cos\phi_0,\qquad C_e=\cos\phi_e.$$

It is clearly evident from the preceding equations that if the earth's magnetic field is removed, the value of τ is zero and consequently ${}_{\|}R_{\perp}={}_{\perp}R_{\|}=0$. In general, however, the reflected waves are elliptically polarized and the polarization ellipse depends on τ. To illustrate the numerical nature of the two most important reflection coefficients, ${}_{\|}R_{\|}$ and ${}_{\|}R_{\perp}$ are shown in Figs. 1–6 (pp. 1627–1631) as a function of the frequency parameter ω/ω_r for fixed values of the angle of incidence. Two values of τ are considered, namely, 0° corresponding to the isotropic ionosphere and 60° which is believed to be of the correct order of magnitude for low radio frequencies. The calculations were carried out using the complete formulas indicated by (2), (3) and (4).

It is interesting to note that the general shapes of the ${}_{\|}R_{\|}$ curves are not appreciably different for the two values of τ. This is particularly true for large angles of incidence. The pronounced dip in the ${}_{\|}R_{\|}$ curves for large angles of incidence is a quasi-Brewster effect where the incident wave is most nearly "matched" to the ionosphere.

C. A Comparison with Experimental Data

It is worthwhile to make a preliminary comparison of the calculated reflection coefficients ${}_{\|}R_{\|}$ and ${}_{\|}R_{\perp}$ with the experimental results at 16 kc taken by Bain, Bracewell, Straker, and Westcott [2]. One of the most striking features of their data was the consistent change of the state of the polarization of the downcoming wave, being nearly circular at short ranges (*i.e.*, when $\phi<30°$) and becoming linear at larger ranges (*i.e.*, when $\phi>60°$). On examining Figs. 2 and 3 it is seen that the phase difference between ${}_{\|}R_{\|}$ and ${}_{\|}R_{\perp}$ for $\phi\leq30°$ is of the order of 100° corresponding to approximately circular polarization for a range of ω/ω_r from about 0.4 to 1.0 or more. Furthermore, from these same curves it is seen that the phase difference, for $\phi\cong80°$, is less than 10°, corresponding to approximately linear polarization.

They also find that $|{}_{\|}R_{\|}/{}_{\|}R_{\perp}|$ is about 1.25 for most of their results. On examining Figs. 2 and 3 it would seem that this would be valid within 20 per cent for angles of incidence $\leq60°$, for ω/ω_r in the range from 0.2 to 0.6. At larger ranges, corresponding say to $\phi=80°$, the ratio would still be near 1.25 if ω/ω_r was somewhat smaller, say 0.1 to 0.3.

It has been found also that the reflection coefficients ${}_{\|}R_{\|}$ on a summer night is of the order of 0.5 both at short and larger ranges (*i.e.*, $\phi<80°$). This would be compatible with Fig. 3(a) if ω/ω_r is anywhere in the range from about 0.05 to 0.3. On the other hand, the reflection coefficient ${}_{\|}R_{\|}$ on a summer day is of the order of 0.2 for short ranges (*i.e.*, $\phi<45°$) and about 0.35 for larger ranges (*i.e.*, $\phi\geq60°$). This most closely corresponds to the curves in Fig. 2 when ω/ω_r is near 0.8.

Values of ω/ω_r at 16 kc that are most nearly representative of a summer night or a summer day could be taken as 0.2 and 0.6, respectively.

D. The Multiple Reflections

The source is now taken to be a vertical electric dipole source located on the surface of the spherical earth. On the basis of geometrical optics, the vertical electric field E in millivolts per meter at range d_{km}, in kilometers, is given by the series

$$E = E_0 e^{-i\Phi_0} + 80.5 \sum_{n=1,2\cdots}^{\infty} \frac{\alpha_n \sin^2 \phi_n (1 + R_{\parallel})^2}{(d_{km} + 300 t_n{}^{ms})} Q_n e^{-i2\pi f_{kc} t_n{}^{ms}}, \tag{5}$$

where

$$Q_1 = {}_{\parallel}R_{\parallel}(\bar{\phi}_1) \tag{6}$$

$$Q_2 = [{}_{\parallel}R_{\parallel}(\bar{\phi}_2)]^2 R_{\parallel}(\phi_2) + {}_{\parallel}R_{\perp}(\bar{\phi}_2) R_{\perp}(\phi_2) {}_{\perp}R_{\parallel}(\bar{\phi}_2) \tag{7}$$

$$\begin{aligned} Q_3 = {} & [{}_{\parallel}R_{\parallel}(\bar{\phi}_3)]^3 [R_{\parallel}(\phi_3)]^2 \\ & + 2\,{}_{\parallel}R_{\parallel}(\bar{\phi}_3) R_{\parallel}(\phi_3) {}_{\parallel}R_{\perp}(\bar{\phi}_3) R_{\perp}(\phi_3) {}_{\perp}R_{\parallel}(\bar{\phi}_3) \\ & + {}_{\parallel}R_{\perp}(\bar{\phi}_3) R_{\perp}(\phi_3) {}_{\perp}R_{\perp}(\bar{\phi}_3) R_{\perp}(\phi_3) {}_{\perp}R_{\parallel}(\bar{\phi}_3), \text{ etc.} \end{aligned} \tag{8}$$

The reflection coefficients with the double suffix have been defined previously and are functions of $\bar{\phi}_n$ which is the angle between the n hop sky ray and the vertical. The factors $R_{\parallel}(\phi_n)$ and $R_{\perp}(\phi_n)$ are the corresponding reflection coefficients for the ground for an angle of incidence of ϕ_n measured from the vertical. They are given by

$$R_{\parallel}(\phi_n) = \frac{N^2 C_n - (N^2 - S_n{}^2)^{1/2}}{N^2 C_n + (N^2 - S_n{}^2)^{1/2}} \tag{9}$$

and

$$R_{\perp}(\phi_n) = \frac{C_n - (N^2 - S_n{}^2)^{1/2}}{C_n + (N^2 - S_n{}^2)^{1/2}} \tag{10}$$

with $C_n = \cos \phi_n$ and

$$S_n = \sin \phi_n,$$

where N is the complex refractive index of the lower medium. The quantities E_0 and Φ_0 are the amplitude and phase of the ground wave and are normalized so that E_0 is 100 mv/m at one mile (1.605 km) to conform with the extensive numerical results recently published [10]. The quantity $t_n{}^{ms}$ is the time in milliseconds for the difference between the path length of the n hop sky wave and a direct ray along the earth's surface. f_{kc} is the operating frequency in kilocycles per second. The remaining α_n in (5) is a convergence coefficient which is a measure of the focusing effect for an n hop ray being confined between concentric spherical surfaces of radius a and $a+h$. This is given by

$$\alpha_n = (1 + h/a) \left[\frac{2n \sin\left(\dfrac{d_{km}}{2an}\right)}{\sin\left(\dfrac{d_{km}}{a}\right)} \right]^{1/2} \cdot \left[\frac{(1 + h/a) - \cos\left(\dfrac{d_{km}}{2an}\right)}{(1 + h/a)\cos\left(\dfrac{d_{km}}{2an}\right) - 1} \right]^{1/2}, \tag{11}$$

where h is the height of the ionosphere and a is the radius of the earth. A derivation is given in Section II.

Formulas are thus available for the complete calculation of the VLF field intensity. In most cases, the effect of the earth's magnetic field is minor if attention is restricted to the vertical electric field. Under this "isotropic" approximation, the factor Q_n in (5) is given by

$$Q_n = [{}_{\parallel}R_{\parallel}(\bar{\phi}_n)]^n [R_{\parallel}(\phi_n)]^{n-1}. \tag{12}$$

Furthermore, for propagation over sea water $R_{\parallel}(\phi_n) \cong -R_{\perp}(\phi_n) \cong 1$ which corresponds to an assumed perfectly-conducting lower boundary. For land, this approximation is not usually justified except for ranges less than about 300 km and $f_{kc} < 20$.

Using the above approximations, the field can be written

$$E = E_0 e^{-i\Phi_0} + \sum_{n=1,2,3\cdots}^{\infty} E_n e^{-i\Phi_n}, \tag{13}$$

where

$$E_n = 321 \frac{|{}_{\parallel}R_{\parallel}(\bar{\phi}_n)|^n \alpha_n \sin^2 \phi_n}{d_{km} + 300 t_n{}^{ms}} \tag{14}$$

and

$$\Phi_n = 2\pi f_{kc} t_n{}^{ms} + n[\text{phase lag of } {}_{\parallel}R_{\parallel}(\bar{\Phi}_n)]. \tag{15}$$

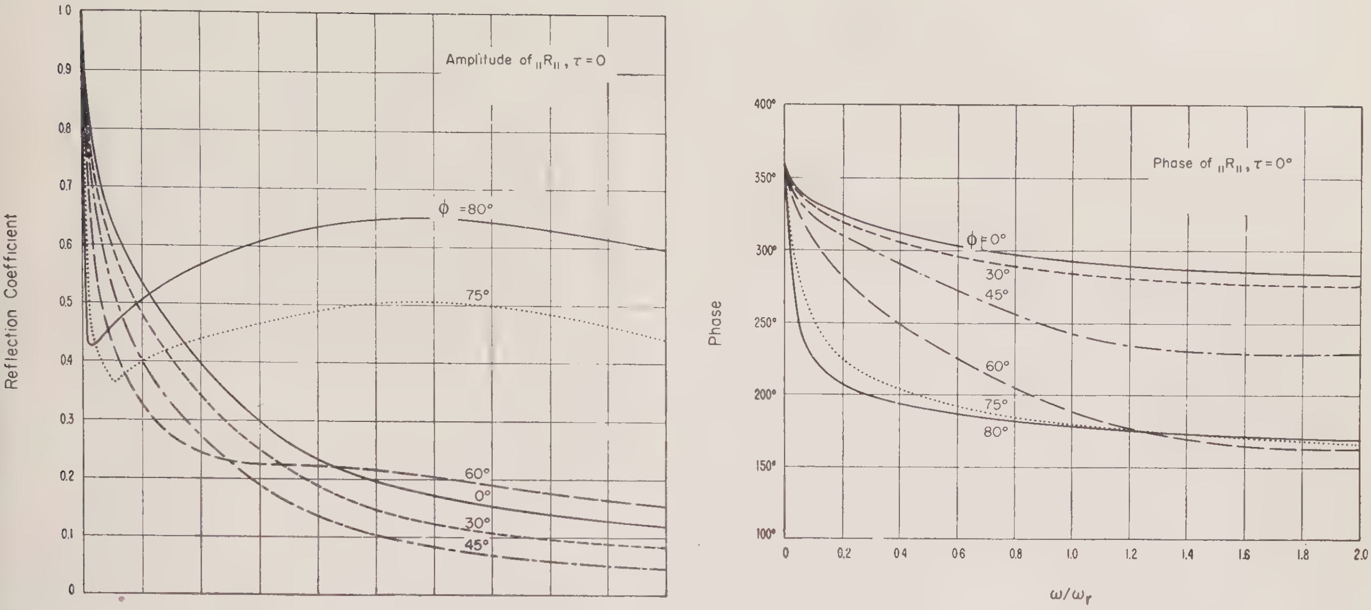
The quantities E_0 and Φ_0 are the amplitude and phase of the ground wave and are plotted in Fig. 4(a) and 4(b) for 10 and 20 kc. The quantities E_n and Φ_n are the amplitude and total phase delay of the resultant nth hop sky wave for vertical-dipole antennas.

The sky wave field amplitude E_n is plotted in Fig. 5(a)–(c) as a function of range for $n = 1$ and 2 and $f_{kc} = 10$ and 20. Various values of the ionospheric parameter ω/ω_r are indicated on the curves. The three sets of curves correspond to heights of 70, 80 and 90 km. The total delay Φ_n of the sky waves is shown in Fig. 6(a)–(c) for the same range of values.

While the above curves are only shown for the first two hops, it is easy to demonstrate that, for the relevant values of ω/ω_r, E_n diminishes rapidly with increasing n. As an example E_n, along with E_0, are shown plotted in Fig. 7 (p. 1631) for $n = 1$, 2, 3 and 4, for $h = 80$ km. It is interesting to note that the ground wave E_0 has the same amplitude as E_1 at about 600 km.

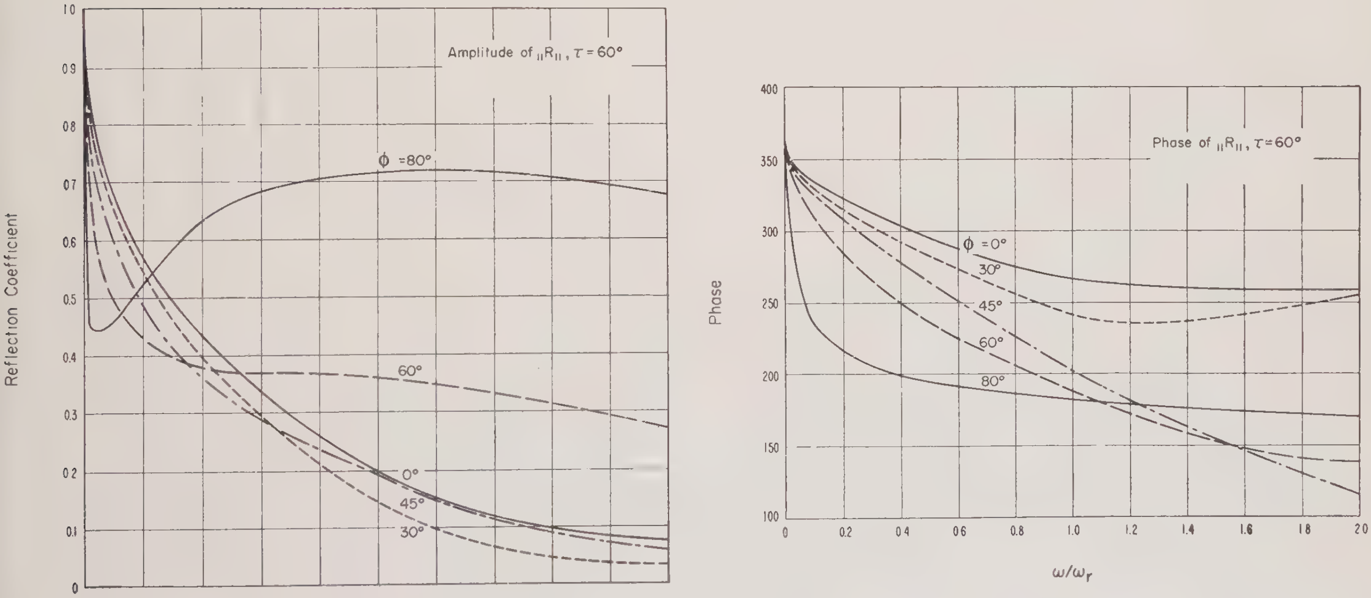
The sky wave amplitude and phase, plotted in the above form, should be quite useful for interpreting experimental results. This is particularly so when the sky waves can be separated from the ground wave.

Using (13) and the computed data of E_0 and E_n, the magnitude of the total field $|E|$ is shown plotted in Fig. 8 as a function of distance for $h = 75$ km and $f_{kc} = 16$. Several values of ω/ω_r are shown. Some experimental points are also shown on the curves which are taken from data acquired by Heritage, Weisbrod, and Bickel [9], on an essentially east to west path over the Pacific Ocean in daytime and in summer. The data seems to fit the curves for $\omega/\omega_r = 0.25$ or 0.50 fairly well, which is in accord with the previously mentioned measurements of reflection coefficients.



(a) (b)

Fig. 1—The amplitude and phase of the reflection coefficient $_{\|}R_{\|}(\phi)$ for $\tau=0$ as a function of ω/ω_r.



(a) (b)

Fig. 2—The amplitude and phase of the reflection coefficient $_{\|}R_{\|}(\phi)$ for $\tau=60°$ as a function of ω/ω_r.

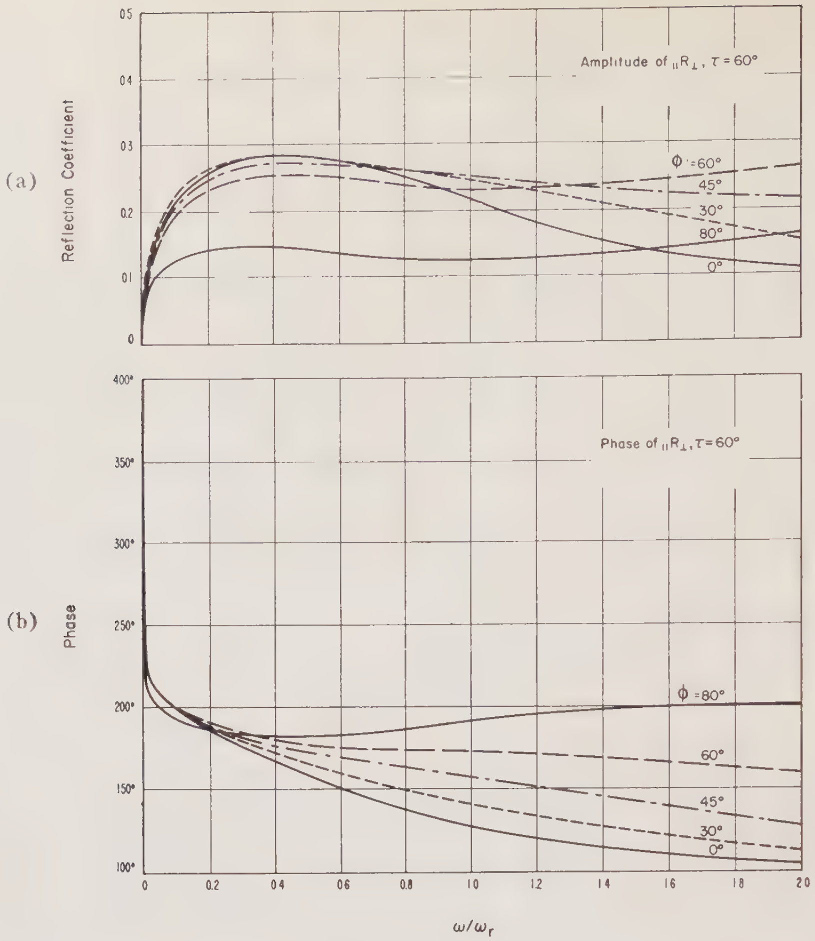


Fig. 3—The amplitude and phase of the conversion coefficient $_{\parallel}R_{\perp}(\phi)$ for $\tau=60°$ as a function of ω/ω_r.

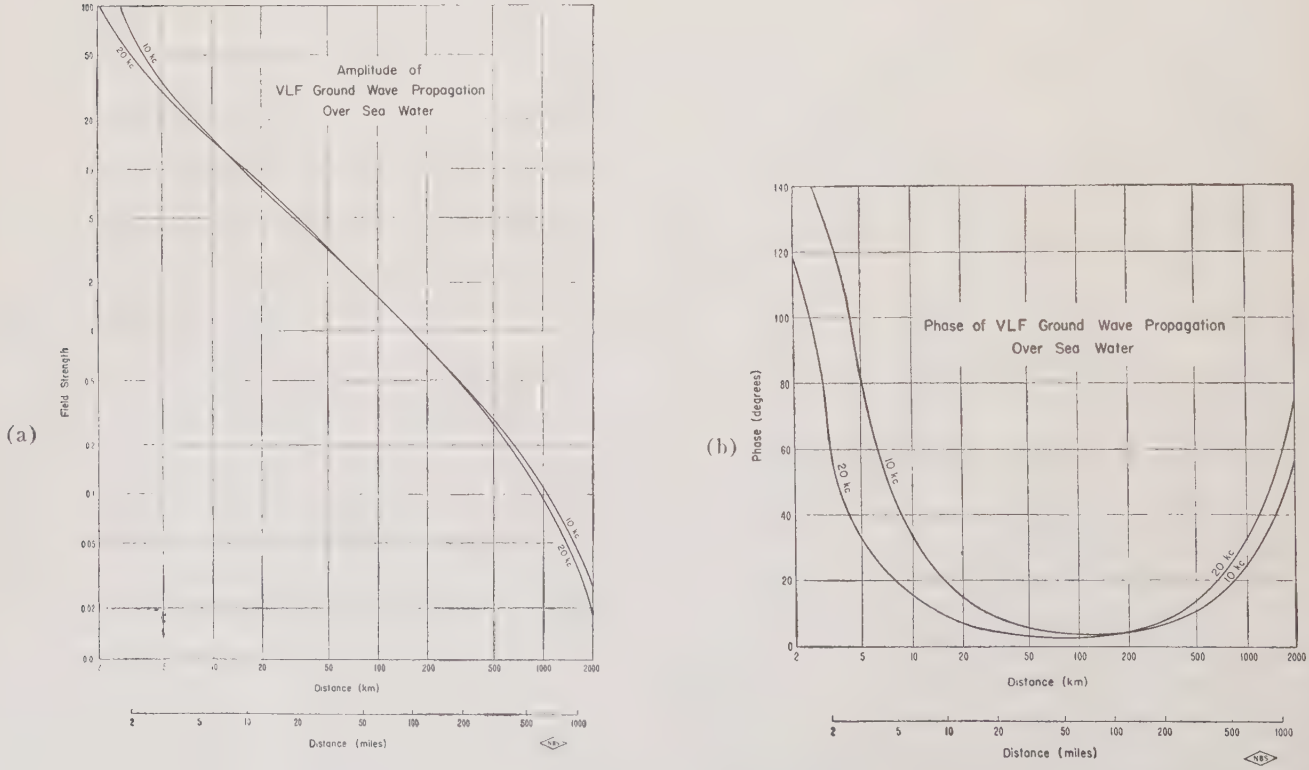
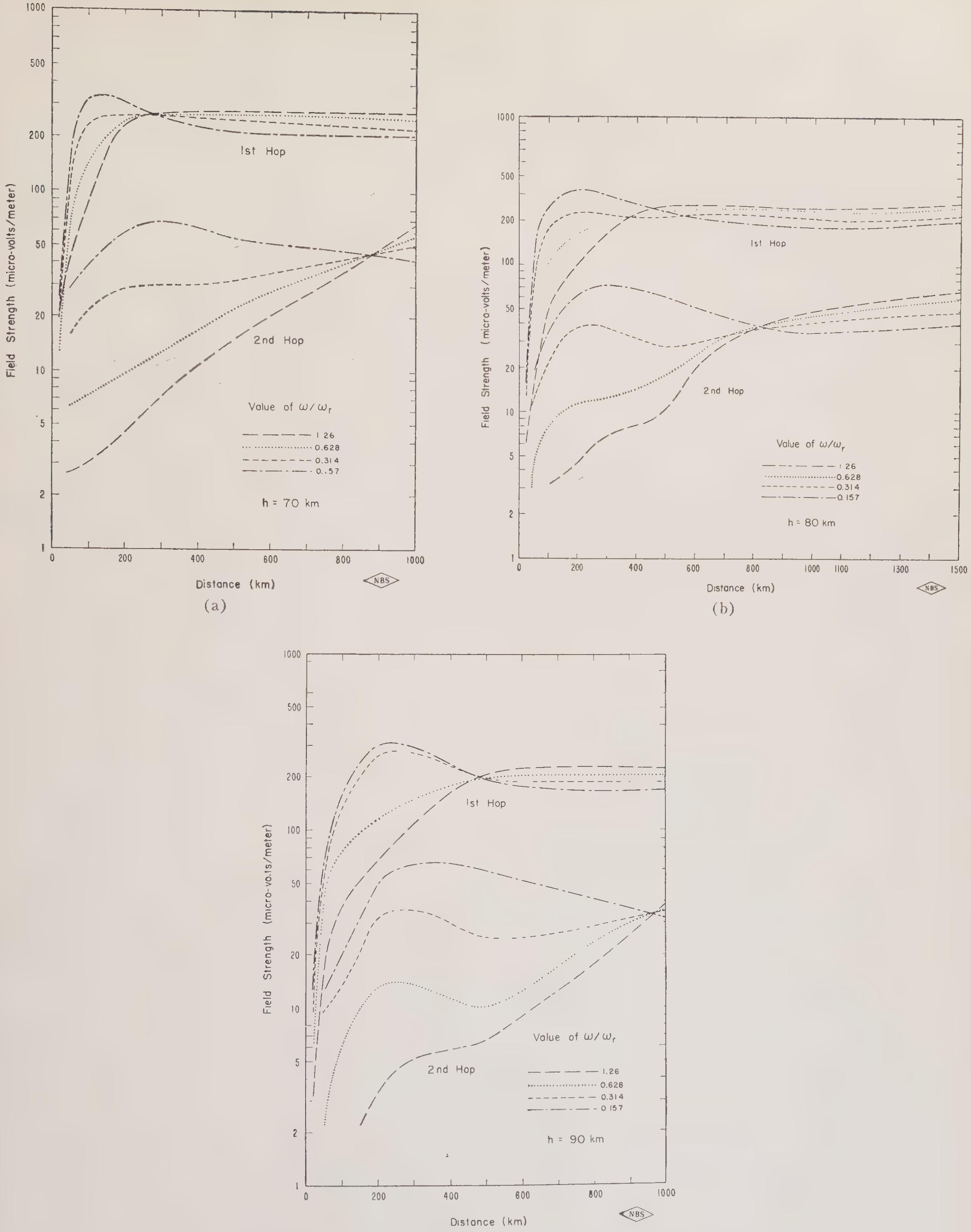


Fig. 4—The amplitude and phase of the ground wave normalized so that the radiation field is 100 mv/m at one mile (1.605 km) and the phase of the radiation field is zero on a flat perfectly conducting earth.



(a)

(b)

(c)

Fig. 5—The resultant amplitude of the vertical electric field of the first two sky waves as a function of range for various values of ω/ω_r and h.

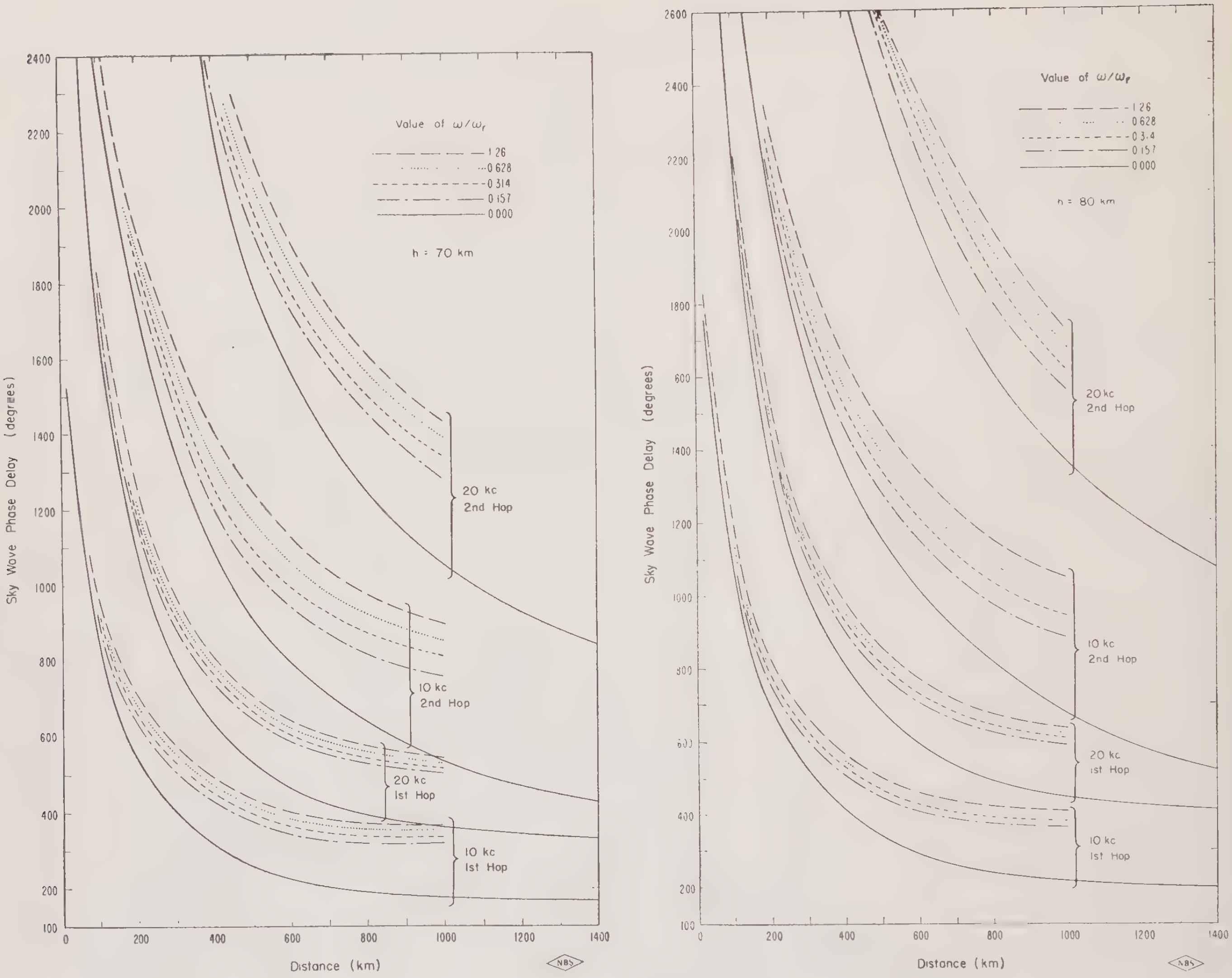


Fig. 6(a)

Fig. 6(b)

Fig. 6—The total phase delay of the first two sky waves relative to the direct ray along the surface of the ground.

(*Fig. 6 Con't next page*)

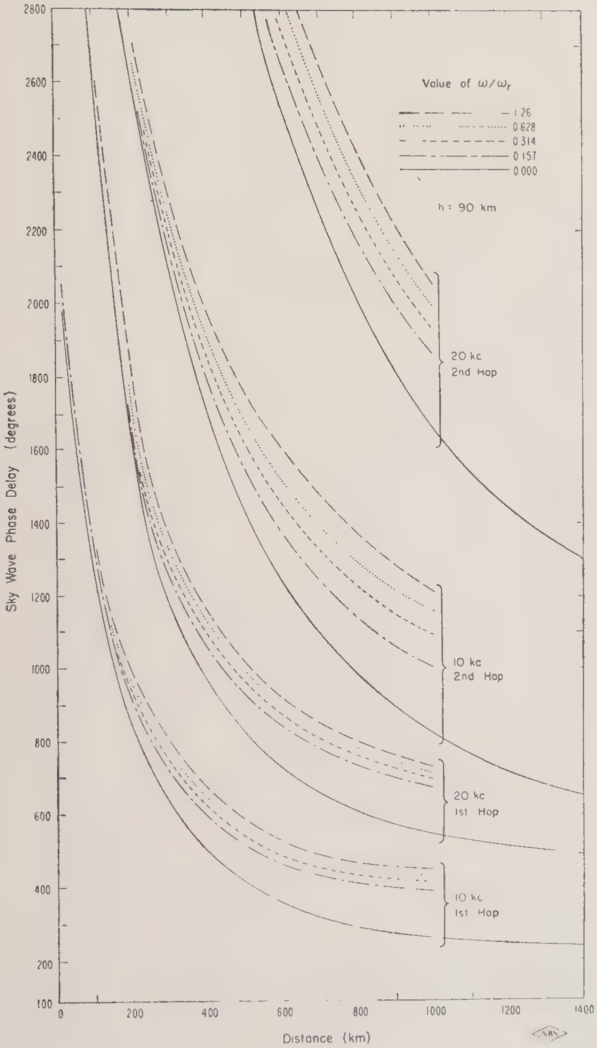


Fig. 6(c)

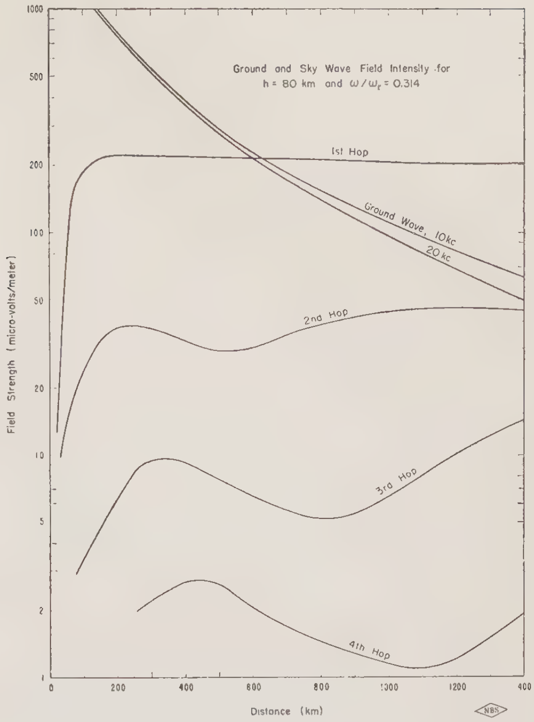


Fig. 7—The amplitudes of the ground wave and the first four sky waves.

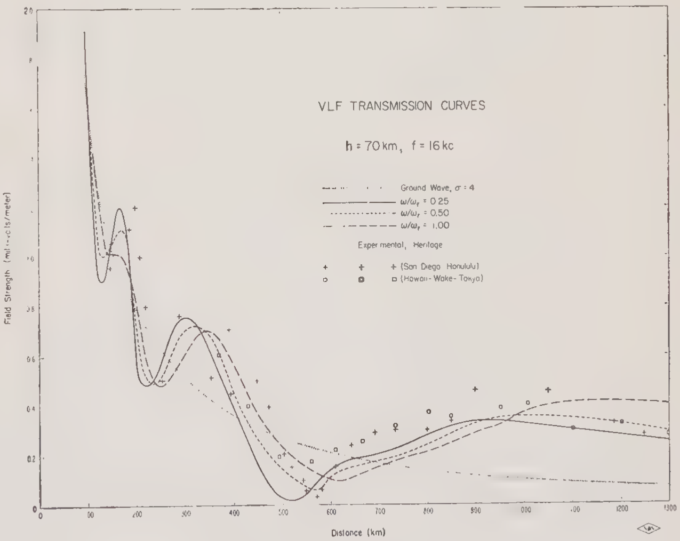


Fig. 8—Field-strength distance curves for 16 kc over an east-west sea water path normalized so that the radiation field is 100 mv/m at 1.605 km.

II. Diffractive Corrections Near Caustics

A. Introduction

The straightforward application of geometrical optics as discussed in Section I has certain limitations which are not entirely obvious. Difficulty is first encountered when the first hop sky wave leaves and returns to the earth tangentially. In this situation, the geometrically optically-computed convergence coefficient becomes infinite. This is a caustic of the system. In this case, it is convenient to introduce a correction factor, which is a function of frequency, to remove the objectionable infinity.

B. The Convergence Coefficient and Caustics

It has proven convenient in many geometrical optical calculations to represent the focussing action of the spherical ionosphere by a convergence coefficient. The geometrical meaning of this quantity is seen easily from the following simple derivation. The model chosen consists of a smooth spherical earth of radius a and a smooth concentric reflecting shell of radius $a+h$; the height of this shell above the earth is h. For the moment, the refractive index of the material between the concentric shells is taken as unity.

The convergence coefficient α is now given by $(q'/q)^{1/2}$, where q represents the actual cross section at P of a narrow pencil of rays leaving the transmitter at Q, and q' the cross section which would exist in the case of undisturbed linear propagation. Some consideration shows that $q' = \hat{R}\sin\phi d\phi d\delta$, where δ is the angle of an individual ray with the plane of the paper in Fig. 9 and $\hat{R}$ is the length of the shortest ray that can be drawn from Q to P with a reflection point at the ionosphere. Now the actual cross section at P is equal to $q = q_r \cos\phi$, where

$$q_r = a^2 \sin\theta d\theta d\delta$$

is the cross section as viewed from the center of the earth. It is now easily shown that

$$\alpha = \left(\frac{q'}{q}\right)^{1/2} = \frac{\hat{R}}{a}\left[\frac{\tan\phi\left|\dfrac{\partial\phi}{\partial\theta}\right|}{\sin\theta}\right]^{1/2} \tag{16}$$

which was derived by Lord Rayleigh [18] in equivalent form. When this is applied to the single hop ray between Q and P shown in Fig. 9 it follows that

$$\alpha = \left(\frac{a+h}{a}\right)\left[\frac{2\sin\dfrac{\theta}{2}}{\sin\theta}\right]^{1/2} \cdot \left[\frac{(h+a) - a\cos\dfrac{\theta}{2}}{(h+a)\cos\dfrac{\theta}{2} - a}\right]^{1/2}, \tag{17}$$

since

$$\tan\phi = \frac{(h+a)\sin(\theta/2)}{(h+a)\cos(\theta/2) - a}\cdot \tag{18}$$

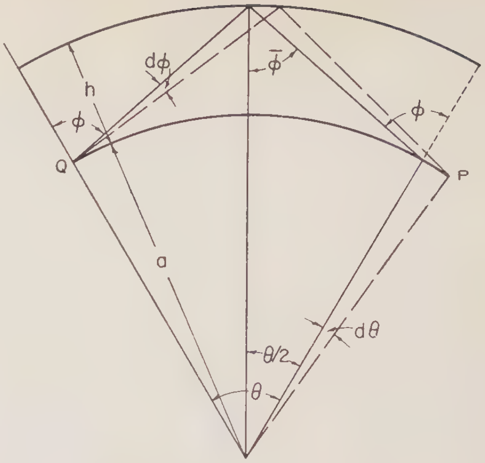


Fig. 9—Geometry for optical calculation of convergence coefficient.

The above expression for the convergence coefficient can be readily generalized to m hops and is expressed by Bremmer [4]

$$\alpha_m = \left(\frac{a+h}{a}\right)\left[\frac{2m\sin\dfrac{\theta}{2m}}{\sin\theta}\right]^{1/2} \cdot \left[\frac{(h+a) - a\cos\dfrac{\theta}{2m}}{(h+a)\cos\dfrac{\theta}{2m} - a}\right]^{1/2} \tag{19}$$

which is identical in form to the single hop formula except that the quantity $\theta/2$ in the expression for α is replaced by $\theta/2m$ except in the factor

$$\sqrt{\sin\theta}$$

in the denominator. Most of the following discussion will be restricted to the single hop case (*i.e.*, $m=1$) but the arguments are easily generalized to the multiple hop case as will be indicated.

The quantity α increases from

$$\frac{a+h}{a}$$

for θ equal to zero to infinity when θ approaches θ_c which is a zero of the denominator of α. θ_c is obtained from

$$\cos\frac{\theta_c}{2} = \frac{a}{a+h} \tag{20}$$

where also $\phi=\pi/2$. In the language of optics, this point is called a caustic. In calculations of field strength by geometrical-optical methods, this infinity at the caustic is usually counteracted by the form of the antenna patterns at the grazing angles $\phi=\pi/2$. This comes about because the vertical patterns, assuming vertical electric dipoles at Q and P, are each $\sin\phi[1+R_{\parallel}(\phi)]$ where $R_{\parallel}(\phi)$ is the Fresnel reflection coefficient at angle of incidence ϕ on the imperfectly conducting ground. At grazing incidence $R_{\parallel}(\phi)$ approaches -1 and since $[1+R_{\parallel}(\phi)]$ occurs twice, the resulting zero is of higher order than the zero in the denominator of the convergence coefficient. Thus Bremmer [4] shows calculations of the sky wave field intensity of the various hops (for a finitely conducting spherical earth and concentric ionosphere) which approach zero at the caustic and remain zero at the caustic and remain zero thereafter. Now if the proper values for the antenna pattern are employed [28] there is no zero in the direction $\phi=\pi/2$ corresponding to grazing incidence and, consequently, the infinity at the caustic is no longer cancelled. It is thus necessary to examine the behavior at the caustic more closely.

There have been numerous discussions of the evaluation of the fields at caustic points. The procedure proposed originally by Debye [8] and later by Picht [17] was to construct appropriate solutions of the wave equation which reduce to the known geometrical optical solution as the wave number k approaches infinity. The problem has been discussed more recently by Luneberg [15] and Kay and Keller [13] who made some useful extensions. On the caustic, the field is quite generally proportional to

$$k^{1/2-1/n} \text{ where } k = 2\pi/\text{wavelength and}$$

where n is an integer greater than 2. Sufficiently far away from the caustic the field is given by geometrical optics and is independent of k. At a perfect focus such as at the antipode in the sphere problem $n=\infty$ and the field is thus proportional to $k^{1/2}$. (More will be said about this case later on.) As it turns out here, the caustic occurring in the convergence coefficient is of the lowest order (namely $n=3$) and consequently the field is proportional to $k^{1/6}$. This is demonstrated as follows.

In a rigorous formulation of the problem, the field of a downcoming wave from a spherical smooth reflector must satisfy the wave equation and, for infinite frequency, transform to the geometrical optical solution. Some consideration shows that in spherical coordinates it must be of the form

$$(kr)^{-1/2}H_{\nu+1/2}(kr)P_{\nu}(-\cos\theta),$$

where $H_{\nu+1/2}$ is a Hankel function and P_{ν} is a Legendre function. Since the asymptotic form of this expression is to be identified with a ray subtending an angle ϕ with the radius vector, it follows that for r near a, $\nu+\frac{1}{2}\sim ka\sin\phi$. It should be noted that if $kr\gg 1$ and $\sin\phi$ is somewhat less than unity, the so-called second-order Debye expansion is valid. That is

$$(kr)^{-1/2}H_{\nu}(kr) \cong \frac{1}{kr}S_{\nu}(kr),$$

where

$$S_{\nu}(z) = \left(1-\frac{n^2}{z^2}\right)^{-1/4} e^{\pm i\int_n^z \left(1-\frac{n^2}{x^2}\right)^{1/2} dx}\, e^{+i\pi/4} \tag{21}$$

and where $n=\nu+\frac{1}{2}$. This is the basic representation from which the geometrical optics representations are derived (see for example [4]). Now when $\nu+\frac{1}{2}$ comes near ka (or n near z), corresponding to ϕ approaching $\pi/2$, it is necessary to use the third-order or Hankel approximation. In this case [25]

$$H_{\nu}(z) \cong \frac{z}{n}\left(1-\frac{n^2}{z^2}\right)^{3/4} H_{1/3}(\rho)e^{\pm i(5/12)\pi-\rho)}S_{\nu}(z), \tag{22}$$

where $H_{1/3}(\rho)$ is the Hankel function of order one-third with argument ρ given by

$$\rho = \frac{n}{3}\left[\frac{z^2}{n^2}-1\right]^{3/2} \tag{23}$$

and as before $n=\nu+\frac{1}{2}$ and $z=ka$. When z is not near n, such that $\rho\gg 1$, the above third-order expression for H_{ν} transforms to the second-order representation on replacing $H_{1/3}(\rho)$ by its leading term in its asymptotic expansion. This indicates that the field at and near the caustic is simply obtained by multiplying the geometrical optical field by a factor $R(\rho)$ which is the ratio of the third-order to the second-order representation of the function $H_{\nu}(z)$. This is given by

$$R(\rho) \cong \left(\frac{\pi\rho}{2}\right)^{1/2} H_{1/3}(\rho)e^{-i(5/12-\rho)} \tag{24}$$

which approaches unity for $\rho\gg 1$. In terms of the angle ϕ

$$\rho \cong \frac{ka\cos^3\phi}{3\sin^2\phi}\,. \tag{25}$$

Near the caustic, ρ is small compared to unity and since

$$H_{1/3}(\rho) \sim \frac{+i2^{1/3}\Gamma(1/3)}{\pi\rho^{1/3}}, \tag{26}$$

it follows that

$$\begin{aligned} R(\rho) &\sim 1.3466\rho^{1/6}e^{+i\pi/12} \\ &\sim 1.3466\left(\frac{ka}{3}\right)^{1/6}\frac{(\cos\phi)^{1/2}}{(\sin\phi)^{1/3}}e^{+i\pi/12}. \end{aligned} \tag{27}$$

In terms of the geometry in Fig. 9

$$(\cos\phi)^{1/2} = \left[\frac{(h+a)\cos\frac{\theta}{2}-a}{(h+a)\sin\frac{\theta}{2}}\right]^{1/2} \tag{28}$$

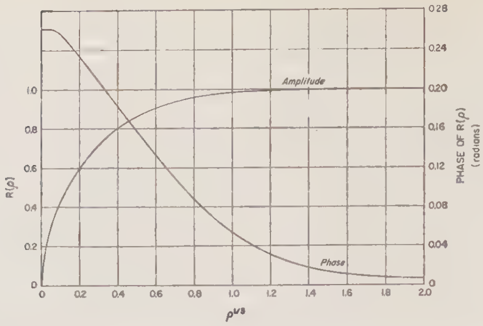


Fig. 10—The correction to geometrical optics near a caustic.

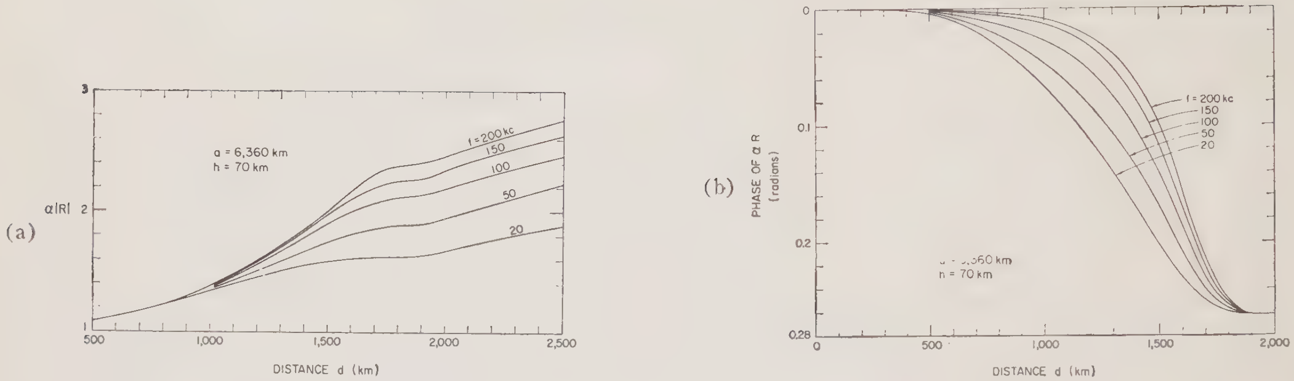


Fig. 11—Convergence coefficient ($m=1$).

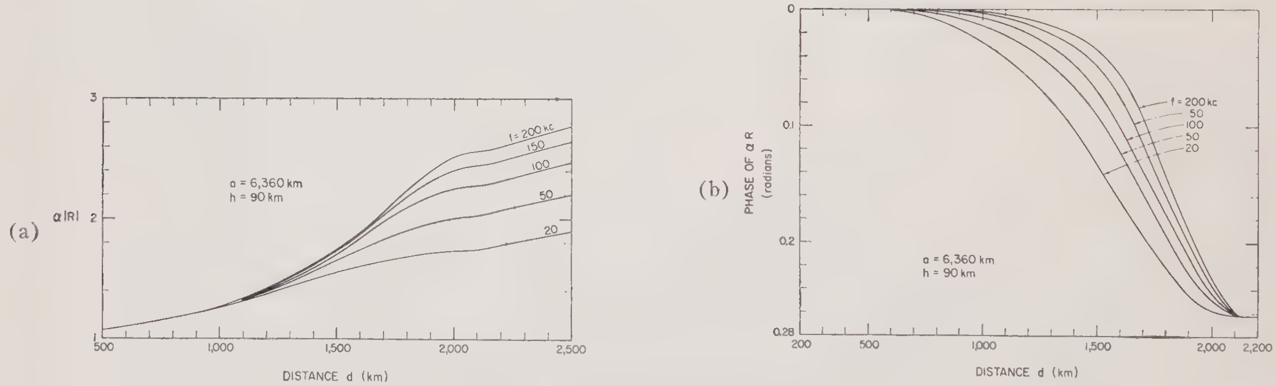


Fig. 12—Convergence coefficient ($m=1$).

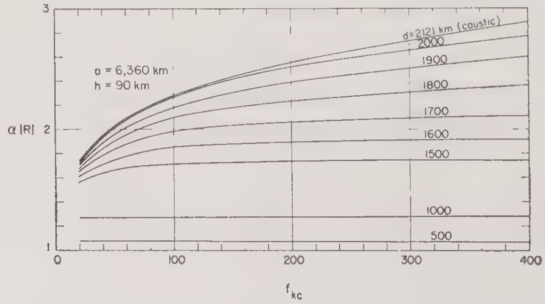


Fig. 13—Convergence coefficient as a function of frequency.

which approaches zero at the caustic in just a way to cancel the infinity in the geometrically optically computed convergence coefficient α.[2] For example on taking the limit

$$(\alpha R)_c = \alpha R]_{\phi\to\pi/2} = \left(\frac{2}{\sin\theta_c}\right)^{1/2} \cdot\left[\left(\frac{a+h}{a}\right)^2 - 1\right]^{1/2} 1.3466\left(\frac{ka}{3}\right)^{1/6} e^{+i\pi/12}. \qquad (29)$$

This quantity which is proportional to the field at the caustic varies as the one-sixth power of the frequency. It is in agreement with a formula obtained by Norton [16] who used a somewhat different method.

It is now clear that the convergence coefficient α in the usual geometrical optical formulas should be replaced by αR which enables the concept to be utilized as described above right up to the caustic. The question now arises as to what happens beyond the caustic. It might be reasoned that the field should decrease beyond this point and the convergence should therefore not increase. Closer inspection indicates however that the convergence as defined does increase. This can be seen by noting that

$$\left|\tan\phi\frac{\partial\phi}{\partial\theta}\right|$$

and R are essentially constant beyond the caustic so that αR varies as

$$\hat{R}(\sin\theta)^{-1/2}.$$

Therefore, beyond the caustic

$$\frac{\alpha R}{(\alpha R_c)} \cong \frac{\hat{R}}{\hat{R}_c}\left(\frac{\sin\theta_c}{\sin\theta}\right)^{1/2}$$
$$\cong \left[\frac{2[(1+h/a)^2-1]^{1/2}+\theta-\theta_c}{2[(1+h/a)^2-1]^{1/2}}\right]\left(\frac{\sin\theta_c}{\sin\theta}\right)^{1/2} \qquad (31)$$

or

$$\alpha R \cong \left(\frac{2}{\sin\theta}\right)^{1/2}\left\{\left[\left(\frac{a+h}{a}\right)^2-1\right]^{1/2} + \left(\frac{\theta-\theta_c}{2}\right)\right\} 1.3466\left(\frac{ka}{3}\right)^{1/6} e^{+i\pi/12}. \qquad (32)$$

To illustrate the significance of the preceding results some quantities have been plotted. The amplitude and phase of the quantity $R(\rho)$ is shown in Fig. 10 as a function of $\rho^{1/3}$. The amplitude and phase of the resultant convergence factor αR is illustrated for various frequencies in Fig. 11(a) and 11(b), respectively, for a reflecting layer height h of 70 km. The corresponding curves are shown in Fig. 12(a) and 12(b) for a height of 90 km.

It can be observed from Fig. 13 that the convergence is generally decreased as the frequency is lowered. In fact, near the caustic the convergence is varying as the one-sixth power of the frequency.

Caution should be exercised in drawing too many conclusions from the shape and behavior of these curves because of the extreme idealizations of the model. The ionospheric reflecting layers are not smooth and the full amount of the convergence would not be realized except possibly at the lowest frequency shown. The influence of roughness has been discussed recently by Norton [16] and the reader is referred to his treatment. Another factor which plays some role is the variation of the refractive index of the atmosphere between the ground and the lower edge of the ionospheric reflecting layer. Methods based on geometrical optics for including this effect have also been developed [16]. Unfortunately, at low frequencies the variation of the refractive index with height is comparable to the wavelength, thus partially invalidating ray tracing.

C. The Complete Geometrical Series with Certain Diffractive Corrections

It is now desirable to actually apply the previous results to the computation of the first hop sky wave. The situation is illustrated in Fig. 14. The surface of the earth is defined by $r=a$ and a smooth reflecting layer is located at $r=a+h$. It is convenient to distinguish three cases. In the first, the receiving antenna located at $R_<$ is illuminated by the one reflected sky wave for the transmitting antenna located at $T_<$. In this situation $\phi<\pi/2$. In the second, the two antennas located at T_c and R_c are located at the critical points where ϕ just

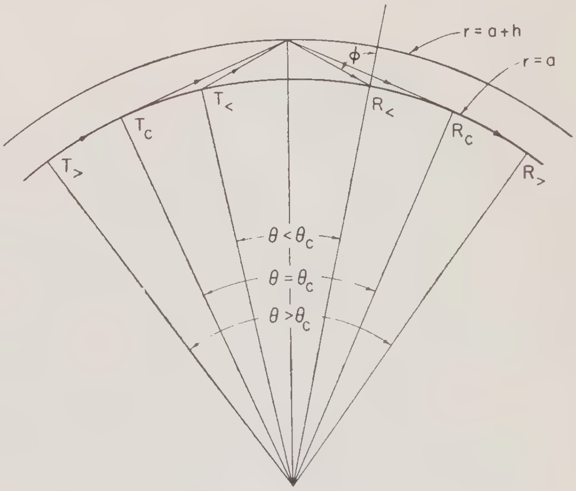


Fig. 14—Ray conception of the first hop sky wave.

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[2] In the case of m hops

$$(\cos\phi)^{1/2} = \left[\frac{(h+a)\cos\dfrac{\theta}{2m} - a}{(h+a)\sin\dfrac{\theta}{2m}}\right]^{1/2}. \qquad (30)$$

becomes $\pi/2$. In the third case, the antenna located at $T_>$ and $R_>$ beyond the critical points such that the first hop sky wave propagates in the diffraction zone or shadow.

The vertical electric field at R for a vertical electric dipole source at T can now be written in the form

$$E = E_0 e^{-i\Phi_0} + 80.5 \sum_m \frac{(\alpha R)_m \sin^2 \phi_m (F)^2}{d_{km} + 300 t_m^{ms}} Q_m e^{-i2\pi f_{kc} t_m^{ms}}. \qquad (33)$$

In the above, E_0 and Φ_0 are the amplitude and phase (lag) of the ground wave normalized such that E_0 is 100 mv/m at one mile (1.609 km); these quantities have been computed and are available in convenient graphical form [10]. $(\alpha R)_m$ is the convergence coefficient defined above for the mth hop sky wave. d_{km} is the distance in kilometers between transmitter and receiver measured along the ground. f_{kc} is the frequency in kilocycles. t_m^{ms} is the time delay in milliseconds between the direct (mth hop) sky wave and the direct wave along the ground (assuming free-space velocity in both cases). Clearly, for the mth hop sky wave

$$300 t_m^{s} = 2m\left[(a+h)^2 + a^2 - 2a(a+h)\cos\frac{\theta}{2m}\right]^{1/2} - a\theta \cdot km$$

which is valid if $\theta < \theta_c$ where θ_c is given by

$$\cos(\theta_c/2) = \frac{a}{a+h}.$$

The same expression also holds for $\theta \geqq \theta_c$ if $m \geqq 2$ and $\theta < \theta_c'$, where θ_c' is given by

$$\cos(\theta_c'/4) = \frac{a}{a+h}.$$

In this case, $300\, t_1^s = a[2\tan(\theta_c/2) - \theta_c]$ km. The case $\theta = \theta_c'$ corresponds to the situation when the second hop sky wave leaves and arrives at the earth tangentially. Without further modification, the theory is not valid there. The factor F, in the above expression, is the cutback factor discussed extensively in another paper [28]. It accounts for the influence of finite conductivity and earth curvature on the resultant pattern of the antennas. When θ is less than but near θ_c, F can be replaced by the factor $[1 + R_{\|}(\phi_m)]$, where $R_{\|}(\phi_m)$ is the Fresnel reflection coefficient for a vertical polarized plane wave incidence at angle ϕ_m on the earth. As stated before, ϕ_m is given by

$$\cos\phi_m = \frac{(h+a)\cos\dfrac{\theta}{2m} - a}{(h+a)\sin\dfrac{\theta}{2m}}.$$

When θ is near θ_c, the more accurate value for the amplitude and phase of F must be employed. These are plotted for various frequencies in Figs. 15 and 16 as a function of $(\theta - \theta_c)/2$ expressed in degrees. When $(\theta - \theta_c)/2$ is sufficiently negative (*i.e.*, the left-hand portion of the figures) the quantity F becomes identical to the Fresnel value. The quantity Q_m involves the reflection coefficient of the ground and the reflection and conversion coefficients at the ionosphere. Its form was discussed in Section I. In the case of the first hop sky wave it becomes simply the reflection coefficient ${}_{\|}R_{\|}(\bar{\phi}_1)$ for a wave incident at angle $\bar{\phi}_1$ at the ionosphere. It might be noted that $(a+h)\sin\bar{\phi}_1 = a\sin\phi_1$.

III. Basic Mode Theory

A. Introduction

In view of the limitations of the optical or ray methods to calculate sky wave field intensities, it is desirable to consider an alternative and more rigorous formulation. As long ago as 1919, Watson presented a formal solution for a dipole source over a spherical homogeneous earth with the ionosphere being represented by a perfectly-conducting concentric shell. More recently Bremmer [4] and Rydbeck [19] have considered the case of a spherically stratified ionosphere. In the case of VLF, the upper boundary can be assumed sharp to a good approximation. This simplifies the approach somewhat and paves the way for a more definite evaluation of the mode characteristics. With this model Schumann [20] has discussed the propagation of AF waves to great distances. Unfortunately his perturbation technique for solving for the mode coefficients is not valid for frequencies above about 800 cps, and certainly cannot be employed for frequencies around 16 kc since the ionosphere is effectively a very poor conductor. Another interesting approach to the problem has been made by Budden [6] who considers the earth and the ionosphere to be represented by a parallel plate waveguide. For some reason which is not entirely clear,[3] he introduces negative-order modes which are barely excited by a vertical dipole source. Nevertheless, his conclusions are largely substantiated by later work [25].

B. Formulation

The earth is considered to be a homogeneous sphere of radius a, of conductivity σ_e and dielectric constant ϵ_e. The ionosphere is then represented by a spherical shell consisting of a homogeneous medium of electron density N and collision frequency g. With respect to a spherical coordinate system (r, θ, ϕ), the earth is bounded by $r = a$ and the shell by $r = b$ and $r = c$. The presence of the earth's magnetic field is neglected here.

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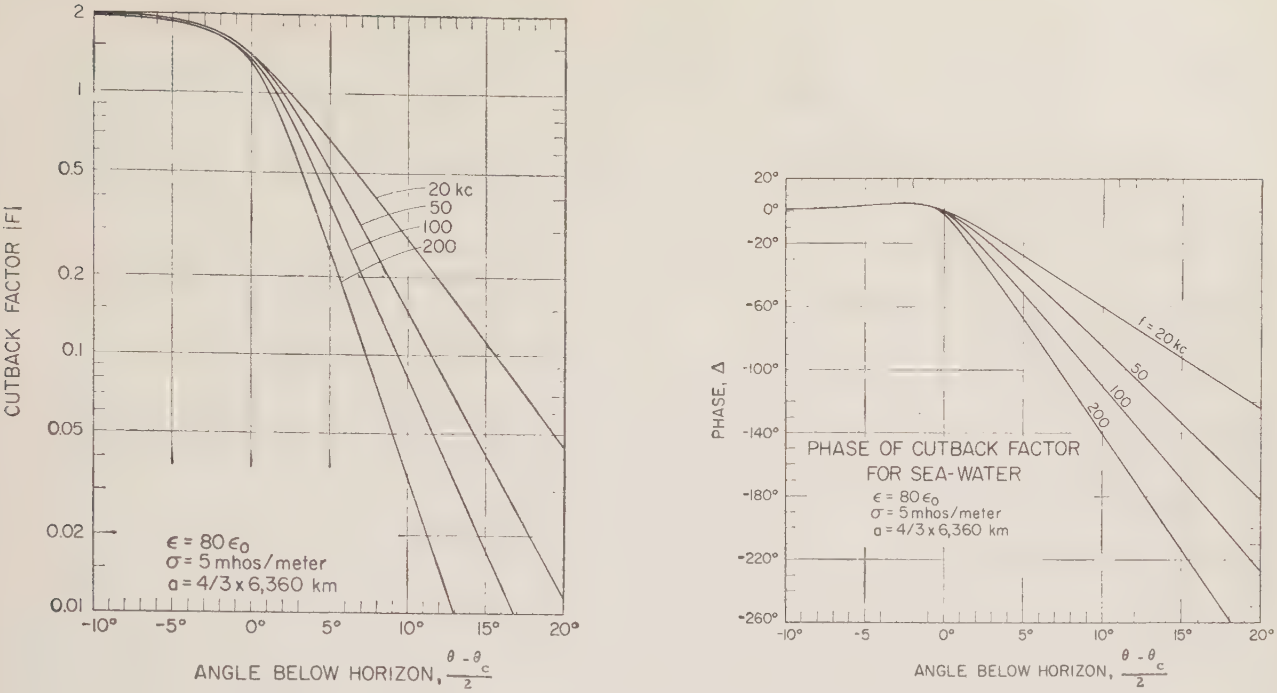
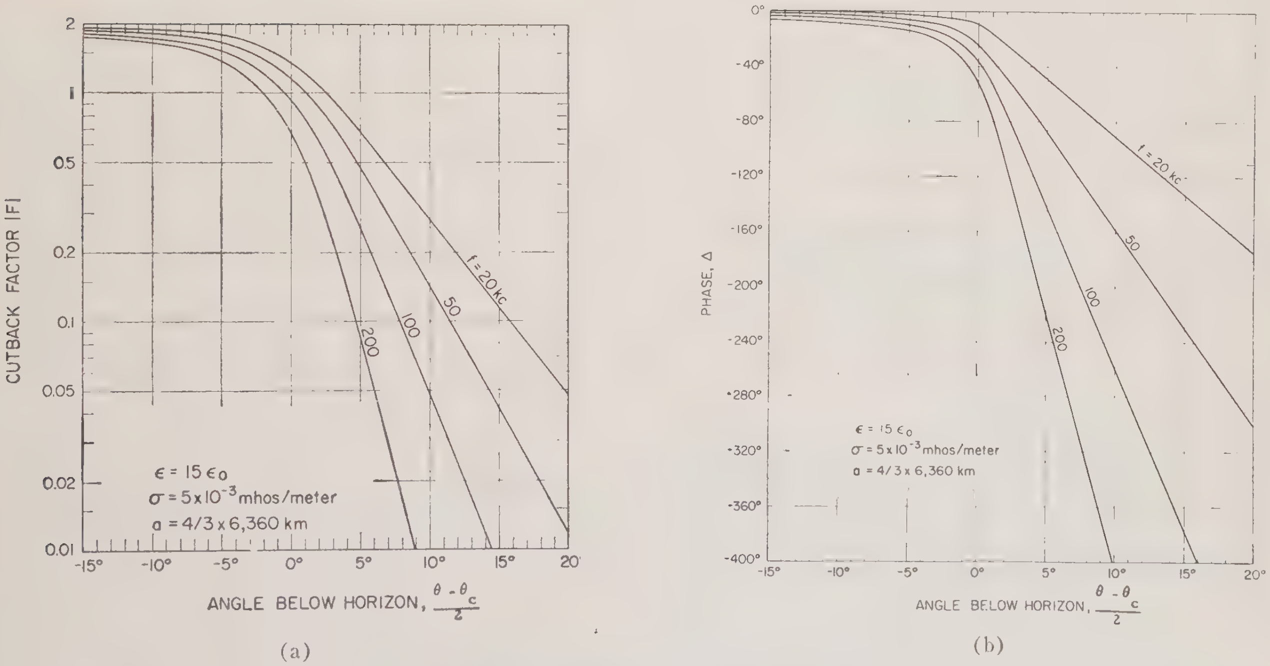
[3] This is due to an error in the deformation of the integration contour. Actually Budden's negative order poles occur on the "wrong" Riemann sheet of the complex plane [26].



(a) (b)

Fig. 15—(a) The cutback factor |F| for sea water. (b) Phase cutback factor for sea water.



(a) (b)

Fig. 16—(a) The cutback factor |F| for average land. (b) Phase of cutback factor for average land.

The origin of the field is assumed to be represented by a vertical electric dipole located at $r=r_0$. If necessary, the source can be generalized to a line distribution of vertical dipoles if the need should arise. In view of the intrinsic spherical symmetry, the fields can be represented in terms of a single scalar function, ψ, as follows:

$$E_r = \frac{i}{r}\,\eta\,\frac{1}{\sin\theta}\,\frac{\partial}{\partial\theta}\left(\sin\theta\,\frac{\partial\psi}{\partial\theta}\right) \tag{34}$$

$$E_\theta = -\frac{i}{r}\,\eta\,\frac{\partial^2}{\partial\theta\partial r}(r\psi) \tag{35}$$

$$H_\phi = -k\frac{\partial\psi}{\partial\theta} \tag{36}$$

and $E_\phi = H_r = H_\theta = 0$, where $\eta = (\mu/\epsilon)^{1/2}$ and $k = (\epsilon\mu)^{1/2}\omega$. In the preceding, the permeability μ is taken to be the same as free space for all of the regions ($\mu = 4\pi \times 10^{-7}$). The complex dielectric constant varies in the following manner:

$$\begin{aligned} \epsilon &= \epsilon_e - i\frac{\sigma_e}{\omega} \quad \text{for } r < a, \\ &= \epsilon \quad \text{for } a < r < b, \\ &= \epsilon_i = 1 - i\frac{\omega_r}{\omega} \quad \text{for } b < r < c, \\ &= \epsilon_0 \quad \text{for } r > c, \end{aligned}$$

where $\omega_r = \omega_0^2/g$ with $\omega_0^2 = Ne^2/m\epsilon$. e and m are the charge and mass of the electron expressed in mks units. A time factor exp $(i\omega t)$ is implied. In general, a subscript e is to be affixed when reference is made to the earth and, correspondingly, a symbol i is to be used for the inner ionospheric shell and a symbol o for the outer medium.

C. General Analysis

The scalar function ψ is a solution of the wave equation appropriate for the regions. The solutions can be represented in terms of spherical wave functions as follows:

$$\begin{aligned} &a_\nu h_\nu^{(1)}(k_e r)P_\nu(-\cos\theta) \quad \text{for } r < a \\ &[b_\nu^{(1)}h_\nu^{(1)}(kr) + b_\nu^{(2)}h_\nu^{(2)}(kr)]P_\nu(-\cos\theta) \quad \text{for } b > r > a \\ &[c_\nu^{(1)}h_\nu^{(1)}(k_i r) + c_\nu^{(2)}h_\nu^{(2)}(k_i r)]P_\nu(-\cos\theta) \quad \text{for } c > r > b \\ &d_\nu h_\nu^{(2)}(k_0 r)P_\nu(-\cos\theta) \quad \text{for } r > c. \end{aligned}$$

In the above

$$h_\nu^{(1,2)}(z) = \left(\frac{\pi}{2z}\right)^{1/2} H_{\nu+1/2}^{(1,2)}(z), \tag{37}$$

where $H_{\nu+1/2}^{(1,2)}(z)$ is the Hankel function of the first or second kind of order $\nu+\frac{1}{2}$ with argument z. $P_\nu(-\cos\theta)$ is the hypergeometric series which is a special case of the hypergeometric function $F(\alpha, \beta, \gamma, z)$, namely,

$$P_\nu(-\cos\theta) = F\left(-\nu, \nu+1, 1, \frac{1+\cos\theta}{2}\right). \tag{38}$$

The reason $P_\nu(-\cos\theta)$ is employed rather than $P_\nu(+\cos\theta)$ is due to the fact that ψ must be regular on a ray $\theta=\pi$ whereas $\theta=0$ is to contain the singularity which is the source of the field. Sommerfeld [21] has pointed out that

$$\left[F\left(-\nu, \nu+1, 1, \frac{1+\cos\theta}{2}\right)\right]_{\theta\to 0} \to \frac{\sin\nu\pi}{\pi}\log\theta^2, \tag{39}$$

which demonstrates the singular nature of ψ along the polar axis.

The quantity ν is to be found from the boundary conditions which state that the tangential fields (E_θ and H_ϕ) are continuous at $r=a$, b and c. This, in turn, requires that

$$\frac{1}{k}\,\frac{\partial(r\psi)}{\partial\theta}$$

and $k\psi$ are continuous. Therefore, six equations are obtained to solve for ν. In order that nontrivial solutions are produced, the six by six determinant of the coefficients must vanish. To reduce the problem to a somewhat more palatable form, the following approximation is employed [21]:

$$\begin{aligned} h_\nu^{(1,2)}(z) &= \sqrt{\frac{\pi}{2z}}\,H_{\nu+1/2}^{(1,2)}(z) \\ &\cong \frac{1}{z\sqrt{\cos\alpha_z}}\exp\left[\pm iz(\cos\alpha_z - \alpha_z\sin\alpha_z) \mp i\pi/4\right], \end{aligned} \tag{40}$$

where $\sin\alpha_z = (\nu+\frac{1}{2})/z$. This representation [21] is known as Debye's generalization of Hankel's asymptotic series. It is valid for $z > |\nu+\frac{1}{2}| \gg 1$. If z approaches ν, or if α_z approaches zero, it is necessary to employ the more general form given by Watson [31];

$$\begin{aligned} H_n^{(1,2)}(z) &= \frac{\cot\alpha_z}{\sqrt{3}}\exp\left[\pm in(\cot\alpha_z - \tfrac{1}{3}\cot^3\alpha_z - \alpha_z)\right] \\ &\quad \cdot H_{1/3}^{(1,2)}\left(\frac{n}{3}\cot^3\alpha_z\right), \end{aligned} \tag{41}$$

where $n=\nu+\frac{1}{2}$. This is valid for $z \geqq |\nu+\frac{1}{2}| \gg 1$. For the following analysis, it will be assumed that the Debye expansion is valid. Therefore

$$\frac{h_\nu^{(2)}(kr)}{h_\nu^{(2)}(ka)} \cong e^{-ik(r-a)\cos\alpha}, \tag{42}$$

where $\sin\alpha \cong (\nu+\frac{1}{2})/ka$ since $(r-a)/a \ll 1$. The other spherical Hankel functions can be simplified in a similar manner. For example,

$$h_\nu^{(1)}(k_e r) \propto e^{ik_e(r-a)\cos\alpha_e}$$

where $\sin\alpha_e = (\nu+\frac{1}{2})/k_e a$, and

$$h_\nu^{(1,2)}(k_i r) \propto e^{\pm ik_i(r-a)\cos\alpha_i}$$

where $\sin\alpha_i = (\nu+\frac{1}{2})/k_i a$.

The application of the boundary conditions then leads in a straightforward way to the following, for the determination of α:

$$R_g R_i = e^{-i2k\cos\alpha\, h} \tag{43}$$

where $h=b-a$ and

$$R_g = \frac{k_e/\cos\alpha_e - k/\cos\alpha}{k_e/\cos\alpha_e + k/\cos\alpha}, \tag{44}$$

and

$$R_i = \frac{(k_i/\cos\alpha_i)Q^{-1} - k/\cos\alpha}{(k_i/\cos\alpha_i)Q^{-1} + k/\cos\alpha} \tag{45}$$

where

$$Q = \frac{(k_i/\cos\alpha_i) + i(k_0/\cos\alpha_0)\tan(k_i s\cos\alpha_i)}{(k_0/\cos\alpha_0) + i(k_i/\cos\alpha_i)\tan(k_i s\cos\alpha_i)} \tag{46}$$

and $s=c-b$.

The solution of the preceding transcendental equation for the determination of $\cos\alpha$, or ν, is the central task. When this is accomplished the ratios between the coefficients a_ν, b_ν, etc., are known. For example, for the air region between the earth and the ionosphere,

$$\frac{b_\nu^{(2)}}{b_\nu^{(1)}} = R_g \tag{47}$$

having inserted the proper values of $\cos\alpha$ and ν.

D. First-Order Perturbation Solution

On the assumption that the earth and the ionosphere are highly conducting media it would seem tempting to treat the space between the earth and the ionosphere by methods similar to those used in waveguide theory. In such a case the effect of the imperfect conductivity of the bounding walls is considered as a first-order perturbation to the lossless mode. For the moment, it will be considered that this method is justified. Therefore, subject to k_e and k_i being large, (43) takes the approximate form

$$1 - 2\frac{k\cos\alpha_e}{k_e\cos\alpha} - 2Q\frac{k\cos\alpha_i}{k_i\cos\alpha} \cong e^{2ikh\cos\alpha}. \tag{48}$$

Since the left-hand side of (48) is near unity, it is desirable to let

$$kh\cos\alpha = \pi n + \delta, \tag{49}$$

where $n=0, 1, 2, \cdots$ and δ is a small number given by

$$\delta \cong i\left[\frac{k\cos\alpha_e}{k_e\cos\alpha} + Q\frac{k\cos\alpha_i}{k_i\cos\alpha}\right]. \tag{50}$$

Now since k_e and $k_i \gg k$, $\cos\alpha_e \cong \cos\alpha_i \cong 1$. For $n=0$, (49) can now be solved directly for $\cos\alpha$ and ν:

$$\nu + \tfrac{1}{2} = ka\sin\alpha \cong ka - i\frac{a}{2h}\left(\frac{k}{k_e} + Q_0\frac{k}{k_i}\right), \tag{51}$$

where $Q_0 = [Q]_{\cos\alpha_i\cong 1}$. In solving for $n\neq 0$, $\cos\alpha$ in the expression δ is replaced by $\pi n+\delta$. Then neglecting higher powers of δ, it follows that for $n\neq 0$

$$\nu + \frac{1}{2} = ka\sin\alpha \cong ka\left[1 - \left(\frac{\pi n}{kh}\right)^2\right]^{1/2}$$
$$- i\frac{a}{h}\left[\frac{k}{k_e} + Q_0\frac{k}{k_i}\right]\frac{1}{\left[1 - \left(\frac{\pi n}{kh}\right)^2\right]^{1/2}}. \tag{52}$$

It should be noted that

$$\frac{k}{k_e} \cong \left|\frac{k}{k_e}\right| e^{i\pi/4} \cong G^{1/2}e^{i\pi/4}, \tag{53}$$

where $G=(\epsilon\omega/\sigma_e)$ and

$$\frac{k}{k_i} \cong \left|\frac{k}{k_i}\right| e^{i\pi/4} \cong L^{1/2}e^{i\pi/4}$$

where $L=\omega/\omega_r$. The equation for the characteristic (eigen) values of ν and $\sin\alpha$, denoted by ν_n and S_n ($n=0$, 1, 2, $\cdots$), is then written

$$\nu_n + \tfrac{1}{2} = kaS_n \cong ka\left[1 - \left(\frac{\pi n}{kh}\right)^2\right]^{1/2}$$
$$- \frac{a}{2h}e^{i(3\pi/4)}(G^{1/2} + Q_0L^{1/2})\frac{\epsilon_n}{\left[1 - \left(\frac{\pi n}{kh}\right)^2\right]^{1/2}}, \tag{54}$$

where $\epsilon_0 = 1$, and $\epsilon_n = 2 (n\neq 0)$. The quantity Q_0 which accounts for the finite thickness of the ionospheric shell is given to this approximation, by

$$Q_0 \cong \frac{k_1 + ik_0\tan(k_i s)}{k_0 + ik_i\tan(k_i s)}. \tag{55}$$

It is seen that if $|k_i s| \gg 1$, $Q_0 \cong 1$. Stated in another way this restriction is $s/\lambda \gg L^{1/2}$ when λ is the free-space wavelength. At a frequency of 1 kc with an assumed value of $\omega_r = 2.36\times 10^5$, $L\cong 0.025$ and therefore $s \gg \lambda/40 = 7.5$ km. At higher frequencies this restriction is less stringent and, therefore, if the frequency under consideration is in the kilocycle region, it is probably permissible to regard the ionospheric shell as being infinite in thickness. The remainder of this paper will be restricted to this case. It should be kept in mind, however, that the results at ULF should take into account the finite thickness of the ionospheric shell.

E. A More Accurate Solution

It is now desirable to return to the transcendental equation in order to obtain a more accurate determination of the characteristic values of cos α which are designated as C_n for $n=0, 1, 2, \cdots$. Assuming that the frequency is sufficiently high to regard $s=\infty$, it can be seen that (43) can now be rewritten

$$\left[\frac{(L-i)C_n-\sqrt{C_n{}^2L^2-iL}}{(L-i)C_n+\sqrt{C_n{}^2L^2-iL}}\right] \cdot\left[\frac{(KG-i)C_n-\sqrt{(K-1)G^2-iG+C_n{}^2G^2}}{(KG-i)C_n+\sqrt{(KG-1)G^2-iG+C_n{}^2G^2}}\right] = e^{4\pi iHC_n}e^{-2\pi in}, \quad (56)$$

where

$$C_n=(1-S_n{}^2)^{1/2}, \qquad L=\frac{\omega}{\omega_r}, \qquad G=\frac{\epsilon\,\omega}{\sigma_e},$$

$$K=\frac{\epsilon_e}{\epsilon} \quad \text{and} \quad H=\frac{h}{\lambda}\cdot$$

The numerical solution of this equation has been programed for an automatic computer and results have been obtained for a wide range of values of L, G, H and n.[4]

For small values of L and G, the first-order perturbation solution can be written as follows:

$$\operatorname{Re} S_n \cong \left[1-\left(\frac{n\lambda}{2h}\right)^2\right]^{1/2} + \frac{\sqrt{G}+\sqrt{L}}{4\sqrt{2\pi}}\,\epsilon_n\left(\frac{\lambda}{h}\right)\left[1-\left(\frac{n\lambda}{2h}\right)^2\right]^{-1/2} \quad (57)$$

and

$$\operatorname{Im} S_n \cong -\frac{\sqrt{G}+\sqrt{L}}{4\sqrt{2\pi}}\,\epsilon_n\left(\frac{\lambda}{h}\right)\left[1-\left(\frac{n\lambda}{2h}\right)^2\right]^{-1/2}, \quad (58)$$

where Re and Im indicate that real and imaginary parts are to be taken. It can be seen from the numerical data that these formulas are only adequate for L and G less than about 0.01. However, these simple relations do provide a good check on the machine calculations since for a specified value of the mode number n, Re S_n and Im S_n should reduce to these limiting forms as L is continuously decreased.

F. Orthogonality Considerations

Before discussing the modes in any further detail, it is perhaps desirable to return to the general expression for the wave function ψ. It can be written in the form [21]

$$\psi(r,\theta)=\sum_n D_\nu z_\nu(kr)P_\nu(-\cos\theta), \quad (59)$$

where the summation is over the various modes numbered from 0 to ∞ through integral values. For the region between the earth and the ionosphere

$$z_\nu(kr)=b_\nu{}^{(1)}h_\nu{}^{(1)}(kr)+b_\nu{}^{(2)}h_\nu{}^{(2)}(kr)$$
$$\cong \text{const.}\times\left[e^{ik(r-a)\cos\alpha}+R_ge^{-ik(r-a)\cos\alpha}\right], \quad (60)$$

where R_g is defined by (44) and is a function of cos α. An alternative, but equivalent representation is

$$z_\nu(kr)\cong \text{const.}\times\left[e^{ik(b-r)\cos\alpha}+R_ie^{-ik(b-r)\cos a}\right]. \quad (61)$$

The important modes are those with small attenuation, that is where the imaginary parts of C_n or S_n are small compared to one. In such cases $R_g\cong 1$ and $R_i\cong\pm 1$ as can be verified from the numerical results. From a physical standpoint, this must be so since incomplete reflection corresponds to high leakage from the mode.

To study the orthogonality properties of the modes, the following integral is considered

$$I=\int_{ka}^{kb} z_\nu(\rho)z_\mu(\rho)d\rho, \quad (62)$$

where ν and μ are two sets of modes. Now the function $z_\nu(\rho)$ satisfies

$$\rho\frac{d^2(\rho z_\nu)}{d\rho^2}+[\rho^2-\nu(\nu+1)]z_\nu=1 \quad (63)$$

and there is a similar equation for z_μ. These two equations are now multiplied by z_μ and z_ν, respectively, and integrated over the domain ka to kb, to obtain

$$I=\frac{\rho\left(z_\mu\dfrac{d}{d\rho}(\rho z_\nu)-z_\nu\dfrac{d}{d\rho}(\rho z_\mu)\right)\Bigg|_{ka}^{kb}}{\nu(\nu+1)-\mu(\mu+1)}\cdot \quad (64)$$

For the important modes, the right-hand side of (64) is negligibly small if $\mu\neq\nu$, since the numerator vanishes at the limits ka and kb when R_g and R_i approach ± 1. For the important case for $\mu=\nu$, a normalization factor is defined by

$$N_\nu=\lim_{\mu\to\nu}\int_{ka}^{kb} z_\mu(\rho)z_\nu(\rho)d\rho \quad (65)$$

$$=\int_{ka}^{kb}[z_\nu(\rho)]^2d\rho\cong 2kh\left[1+\frac{\sin(2khC_n)}{2khC_n}\right]. \quad (66)$$

It should be remarked at this point that the modes are not strictly orthogonal since the right-hand side of (64) does not vanish identically although it is small compared to N_ν. As the conductivity of the bounding walls approaches infinity the modes would be completely orthogonal.

---

[4] The program for the machine calculation was devised by Dr. Howe and has been reported elsewhere [29].

Multiplying both sides of (59) by $z_\mu(kr)$ and then integrating with respect to kr from ka to kb, leads to the following formula for D_ν:

$$D_\nu = \frac{1}{N_\nu P_\nu(-\cos\theta)} \int_{ka}^{kb} z_\nu(kr)\psi(r,\theta)dr. \tag{67}$$

To actually evaluate D_ν, it is desirable to let $r \to r_0$ and $\theta \to 0$, in which case

$$\psi(r,\theta) \to \psi_0(r,\theta),$$

where ψ_0 is the primary influence which is singular at $(r_0, 0)$. For a vertical electric dipole consisting of an infinitesimal element of length ds and carrying a current I, it is well known that

$$\psi_0(r,\theta) = \frac{Ids}{4\pi r_0 k} \frac{e^{-ikR}}{R} \tag{68}$$

where $R = [r_0^2 + r^2 - 2rr_0 \cos\theta]^{1/2}$.

Following the process suggested by Sommerfeld [21] for the determination of the Green's function for the perfectly conducting sphere, the integration in (67) is carried out in the immediate neighborhood of the source. For example,

$$r = r_0(1+\eta)$$

where $-\epsilon < \eta < +\epsilon$, $\epsilon \ll 1$ and $dr = r_0 d\eta$, $z_\nu(kr) \eqsim z_\nu(kr_0)$, $e^{-ikR} \eqsim 1$, while

$$\frac{1}{R} \eqsim \frac{1}{r_0}\left[(1+\eta)^2 + 1 - 2(1+\eta)\left(1 - \frac{\theta^2}{2}\right)\right]^{-1/2}$$

$$\cong \frac{1}{r_0(\eta^2+\theta^2)^{1/2}}.$$

Therefore

$$N_\nu D_\nu \eqsim \frac{Ids}{4\pi r_0} z_\nu(kr_0) \lim_{\theta\to 0}$$

$$\cdot \left[\frac{1}{P_\nu(-\cos\theta)} \int_{-\epsilon}^{+\epsilon} \frac{d\eta}{(\eta^2+\theta^2)^{1/2}}\right]. \tag{69}$$

Now

$$\lim_{\theta\to 0}[P_\nu(-\cos\theta)] \to \frac{\sin\nu\pi}{\pi}\log\theta^2 \tag{70}$$

and

$$\lim_{\theta\to 0}\int_{-\epsilon}^{+\epsilon}\frac{dn}{(\eta^2+\theta^2)^{1/2}}$$

$$= \lim_{\theta\to 0}\{\log[\epsilon + \sqrt{\epsilon^2+\theta^2}] - \log[\epsilon + \sqrt{\epsilon^2+\theta^2}]\}$$

$$\to \log\theta^2. \tag{71}$$

It then follows that

$$D_\nu = \frac{1}{2kh} \frac{z_\nu(kr_0)}{\sin\nu\pi} \frac{Ids}{4r_0}. \tag{72}$$

In the above, $z_\nu(kr_0) \cong 2\cos[k(r_0 - a)C_n]$ since $R_g \cong 1$. Furthermore

$$z_\nu(kr) \cong 2\cos[k(r-a)C_n].$$

The field, in terms of the potential function, is then given by

$$\psi(r,\theta) = \frac{Ids}{4khr_0} \sum_{n=0,1,2\cdots}^{\infty} \delta_n \cos(kh_0C_n)$$

$$\cdot\cos(kh_1C_n)\frac{P_\nu(-\cos\theta)}{\sin\nu\pi}, \tag{73}$$

where $h_0 = r_0 - a$ is the height of the source, $h_1 = r - a$ is the height of the observer, $\nu \cong kaS_n$, and

$$\delta_n = \left[1 + \frac{\sin(2kC_nh)}{2kC_nh}\right]^{-1}.$$

G. Simplified Expressions for the Field

The radial field component is of most practical interest and therefore attention will be confined to it. Since

$$E_r = \frac{i}{r}\eta\frac{1}{\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\frac{\partial\psi}{\partial\theta}\right) \tag{74}$$

and

$$\frac{1}{\sin\theta}\frac{\partial}{\partial\theta}\left[\sin\theta\frac{\partial P_\nu(-\cos\theta)}{\partial\theta}\right]$$

$$+ \nu(\nu+1)P_\nu(-\cos\theta) = 0, \tag{75}$$

it follows that

$$E_r = \frac{I\,ds\,i\,\eta}{4khr_0r}\sum_n^\infty \delta_n\cos(kh_0C_n)$$

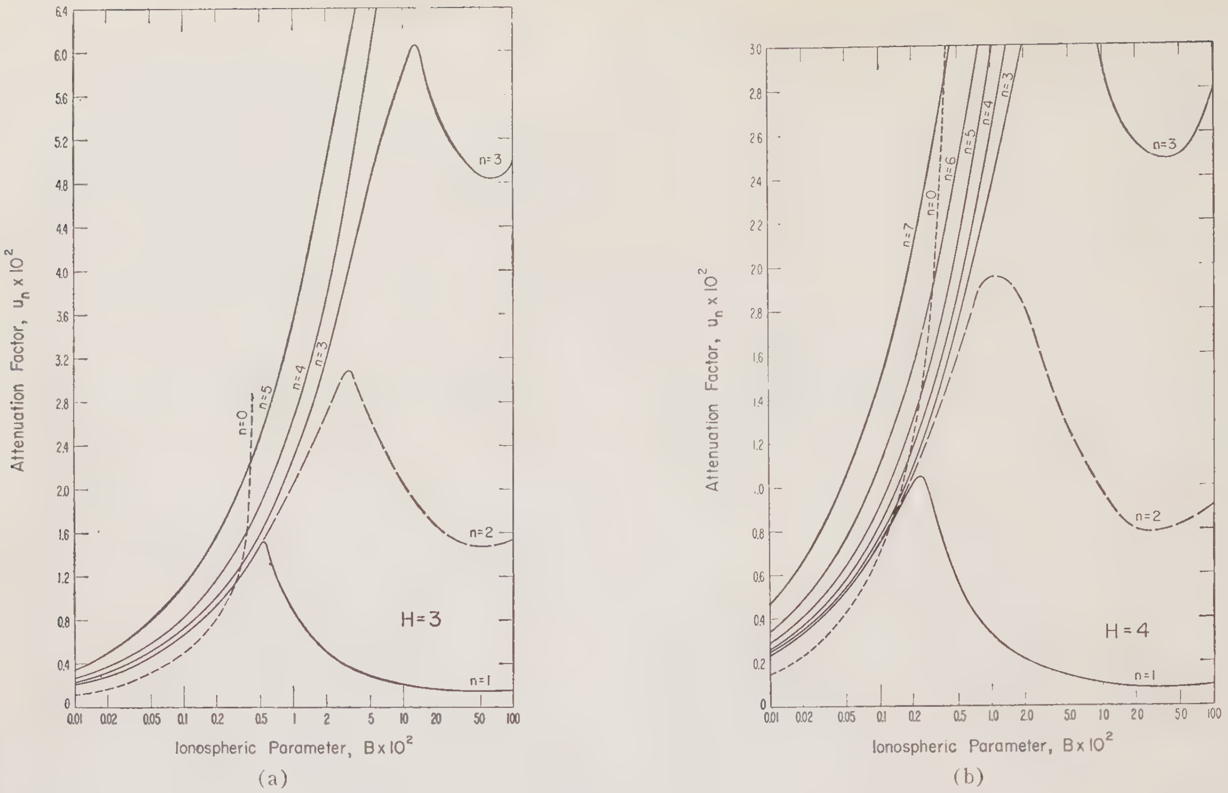
$$\cdot\cos(khC_n)\frac{\nu(\nu+1)}{\sin\nu\pi}P_\nu(-\cos\theta) \tag{76}$$

with $\nu \cong kaS_n$. This is the final solution of the problem and is valid for the air space between the earth and the ionosphere.

For purposes of computation several simplifications can be made. The asymptotic expansion for the Legendre function, given by

$$P_\nu(-\cos\theta) \cong \left(\frac{2}{\pi\nu\sin\theta}\right)^{1/2}$$

$$\cdot\cos\left[\left(\nu+\frac{1}{2}\right)(\pi-\theta) - \frac{\pi}{4}\right], \tag{77}$$



(a) (b)

Fig. 17.

is valid if $|\nu| \gg 1$ and θ not near 0 or π. Since the imaginary part of $\nu(\pi-\theta)$ is also large for $\pi-\theta$ greater than about 10^0 or 20^0, it follows that

$$P_\nu(-\cos\theta)$$

$$\cong \left(\frac{1}{2\pi\nu\sin\theta}\right)^{1/2} \exp\left[i(\nu+\tfrac{1}{2})(\pi-\theta)-i\pi/4\right]. \quad (78)$$

Furthermore the source and observer heights are usually sufficiently low so that kh_0C_n and $kh_1C_n \ll 1$ and $r_0 \cong r \cong a$.

The simplified form of the field can now be written

$$E_r = \mathcal{E}_0\left[\frac{d/a}{\sin d/a}\right]^{1/2} \frac{(d/\lambda)^{1/2}}{(h/\lambda)} e^{i[2\pi d/\lambda - \pi/4]}$$

$$\cdot \sum_{n=0}^{\infty} S_n{}^{3/2}\delta_n e^{-i2\pi S_n(d/\lambda)}, \quad (79)$$

where $d=a\theta$, the arc length between the source and the observer, λ is the free-space wavelength and $S_n = (1-C_n{}^2)^{1/2}$. $\mathcal{E}_0$ is the field of the source on a distance d on a flat perfectly-conducting earth. For $d/\lambda \gg 1$,

$$\mathcal{E}_0 = i(\eta/\lambda)Ids(e^{-i2\pi d/\lambda})/d. \quad (80)$$

It is convenient to normalize such that $\mathcal{E}_0 = 0.10$ v/m for $d=1$ mile $=1605$ m and consequently for purposes of plotting numerical results $\mathcal{E}_0$ in (79) is replaced by $160.5/d$. In most cases of practical interest $\delta_0 \cong \frac{1}{2}$ and $\delta_n \cong 1$ for $n=1, 2, 3 \cdots$.

H. Discussion of Numerical Results

The all-important exponential in the summation of (79) can be rewritten as follows:

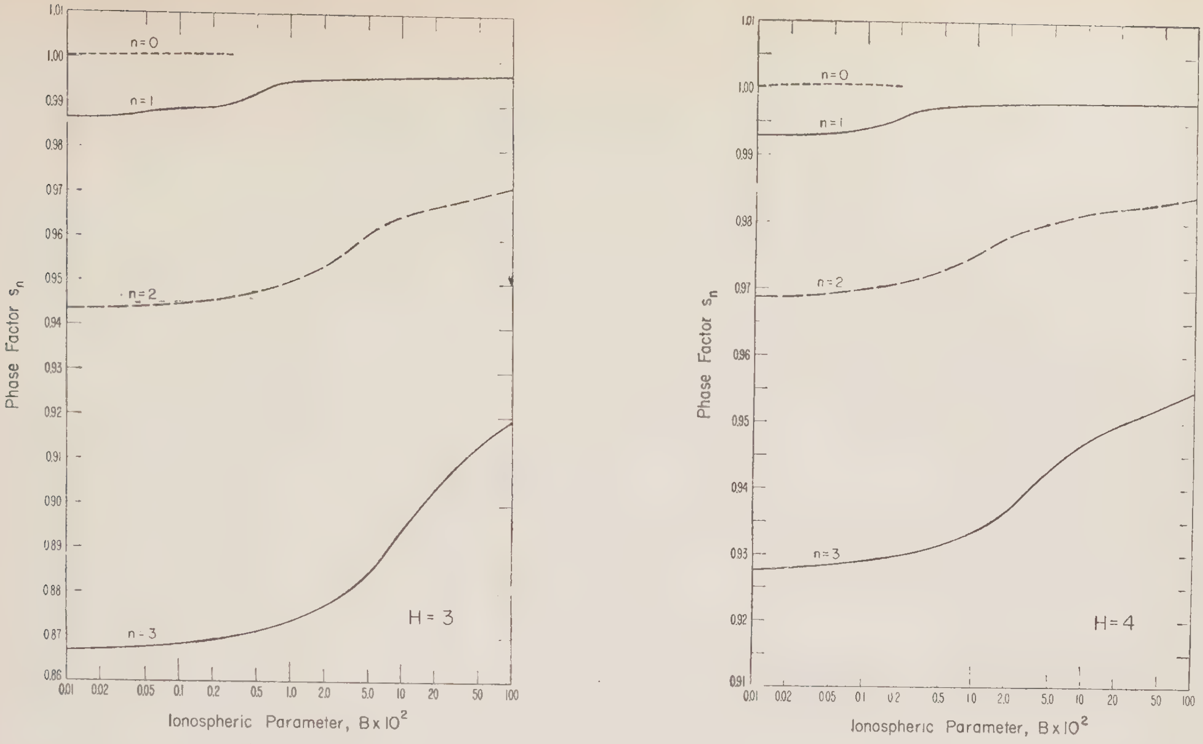
$$\exp\left[-i2\pi S_n(d/\lambda)\right] = \exp\left[-\frac{2\pi d}{h}u_n\right]\exp\left[-\frac{i2\pi d}{\lambda}s_n\right],$$

where $u_n = -\text{Im}\ S_nH = -\text{Im}\ S_n(h/\lambda)$, and $s_n = \text{Re}\ S_n$. u_n is a measure of the attenuation of the mode per unit distance whereas s_n is a dimensionless phase factor. Employing numerical values extracted from the machine-computed data, u_n is plotted in Fig. 17(a) and 17(b) for $H=3$ and 4, respectively, as a function of

$$B\left(=L/H=\frac{2\pi c}{\omega_r h}\right).$$

The corresponding results for S_n are plotted in Fig. 18(a) and 18(b). In the above cases the lower boundary has been assumed to be a perfect conductor ($\sigma_e = \infty$) and therefore $G=0$. This is justified for propagation over sea water at VLF.

The abscissas in Figs. 17 and 18 can be regarded as a parameter which is inversely proportional to the effective conductivity of the ionosphere. For small values of B, the attenuation rates are directly proportional to the square root of B in conformity with first-order perturbation theory. It is most interesting to note that the zero-order mode has an attenuation which becomes pro-



(a)

(b)

Fig. 18.

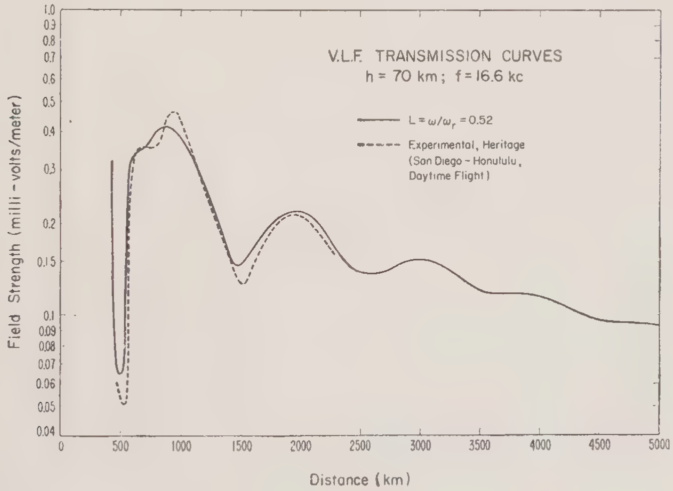


Fig. 19.

hibitively high for the larger B values. The attenuation rate for the nonzero-order modes, on the other hand, reaches a maximum for some intermediate value of B. For larger values of B, the attenuation becomes quite small in the case of first- and second-order modes.

The low attenuation rate for the nonzero-order modes for the larger B values has a simple physical basis. In this case the reflection coefficient R_i is near -1 and hence the upper boundary is behaving much like a good magnetic conductor and consequently there is small energy absorption. Of course, in such a case the zero-order mode is nonpropagating. The maxima in the attenuation curves are quasi-Brewster effects and occur where the waves associated with a given mode are most nearly matched to the upper boundary. As the mode number increases, the angle of incidence of the modal rays becomes steeper and consequently a larger value of B is required to attain the Brewster maximum.

To illustrate the application of these results, the field strength as a function of distance is plotted in Fig. 19. For this computation (79) was employed for a frequency of 16.6 kc, $h=70$ km, $L=\omega/\omega_r=0.52$, and $\sigma_e=\infty$. An experimental curve is also shown which is based on data obtained by Heritage, Weisbrod, and Bickel [9] for a daytime path from San Diego to Honolulu. The rather close agreement here is not accidental. A large number of theoretical curves for various values of ω/ω_r were plotted in a similar manner and the best one selected for presentation here.

I. Conclusion

The mode theory of VLF propagation is seen to be a natural complement to the ray-optical methods discussed in Sections I and II. The results presented here have particular application to propagation over sea water since the conductivity of the lower boundary is assumed infinite. For propagation over land, this is not a valid assumption for frequencies around 16 kc. In fact the attenuation rate u_1 of the first mode can be increased by a factor of 2 or so for an all-land path of average conductivity [25].

A very important limitation of the present results is connected with the use of the Debye or second-order representation for the rigorous spherical wave functions. In terms of C this means that

$$|C| \gg \left(\frac{2}{ka}\right)^{1/3} \text{ in addition to } |C^2| \gg \frac{h}{a}\cdot$$

These conditions are seriously violated for the dominant ($n=1$) mode at the high end of the VLF range. To obtain accurate values of S_1 requires that the wave functions be approximated by the Watson representation given by (41) or an equivalent form in terms of Airy functions. Some progress in this direction has recently been made [22], [25] and [30].

IV. SOME EXTENSIONS TO MODE THEORY

A. Introduction

Most of the calculations of waveguide modes in VLF propagation have been restricted to a sharply-bounded ionosphere. The ionized region is assumed to be semi-infinite in extent. Although such a model has been quite satisfactory in explaining a large body of experimental data in the frequency range from 1 to 20 kc [25], the model is refined by representing it by two discrete layers. This two-layer model removes the objection that the effective conductivity of the homogeneous ionosphere is not constant with respect to frequency. In principle, the method can easily be applied to a stratified ionosphere of any number of layers [26].

B. The Two-Layer Model

The earth is taken to be a homogeneous sphere of conductivity σ_e and dielectric constant ϵ_e. The lower edge of the ionosphere is taken to be at a height h and the collisional frequency ν_1 and the plasma frequency ω_1 are homogeneous up to a height $h+d$ whereupon they change abruptly to ν_2 and ω_2, respectively. The situation is illustrated in Fig. 20.

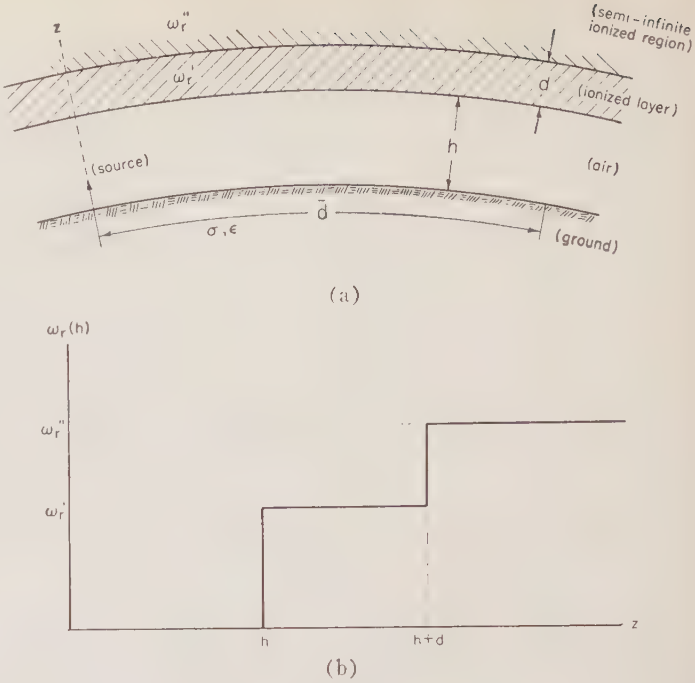


Fig. 20—(a) Stratified model for ionosphere. (b) ω_r as a function of height for the stratified model.

Assuming that the source is a vertical dipole radiating P kilowatts, the vertical electric field in millivolts per meter at the great circle distance $\bar{d}$ in km is well approximated by the mode sum [26].

$$E = E_0W$$

where

$$W = \left[\frac{(\bar{d}/a)}{\sin(\bar{d}/a)}\right]^{1/2} \frac{(\bar{d}/\lambda)^{1/2}}{(h/\lambda)} e^{i[2\pi\bar{d}/\lambda - \pi/4]}$$

$$\cdot \sum_{n=0}^{\infty} \delta_n S_n^{3/2} e^{-2\pi S_n(\bar{d}/\lambda)i},$$

$$E_0 = \frac{300\sqrt{P}}{\bar{d}}, \qquad \delta_n = \left[1 - \frac{\sin(4\pi C_n h/\lambda)}{(4\pi C_n h/\lambda)}\right]^{-1} \tag{81}$$

where $S_n = (1-C_n^2)^{1/2}$, and C_n is a solution of

$$R_g(C)\bar{R}_i(C)\exp(-4\pi iCh/\lambda) = \exp(-i2\pi n), \tag{82}$$

where $R_g(C)$ is the Fresnel reflection coefficient at the ground for a plane wave whose (complex) angle of incidence is the arc-cosine of C, and $\bar{R}_i(C)$ is the corresponding Fresnel reflection coefficient at the lower edge of the ionosphere.

It follows from Section III that

$$R_g(C) = \frac{(KG-i)C - [(K-1)G^2 - iG + C^2G^2]^{1/2}}{(KG-i)C + [(K-1)G^2 - iG + C^2G^2]^{1/2}}, \tag{83}$$

where

$$K = \epsilon_e/\epsilon \quad \text{and} \quad G = \frac{\epsilon\omega}{\sigma}$$

and

$$\bar{R}_i(C) = \frac{N_1^2C - (N_1^2 - S^2)^{1/2}Q}{N_1^2C + (N_1^2 - S^2)^{1/2}Q}, \tag{84}$$

with

$$Q = \frac{N_1^2(N_2^2 - S^2)^{1/2} + N_2^2(N_1^2 - S^2)^{1/2} \tanh\left[i2\pi(d/\lambda)(N_1^2 - S^2)^{1/2}\right]}{N_2^2(N_1^2 - S^2)^{1/2} + N_1^2(N_2^2 - S^2)^{1/2} \tanh\left[i2\pi(d/\lambda)(N_1^2 - S^2)^{1/2}\right]}, \tag{85}$$

where

$$N_1^2 \cong 1 - i/L_1 = 1 - i(\omega_r'/\omega), \qquad \omega_r' = \omega_1^2/\nu_1$$

$$N_2^2 \cong 1 - i/L_2 = 1 - i(\omega_r''/\omega), \qquad \omega_r'' = \omega_2^2/\nu_2.$$

These expressions for the effective refractive index which tacitly neglect the earth's magnetic field are valid for VLF and small values of C [26].

The complex values of S_n ($n=0, 1, 2, \cdots$) satisfying (81) have been obtained from an automatic computer using a program devised by Dr. H. H. Howe.

When L_1 and L_2 are small compared with unity, it was shown previously that

$$S_n \cong \left[1 - \left(\frac{\lambda n}{2h}\right)^2\right]^{1/2} - \frac{\lambda}{4\pi h} e^{i3\pi/4}(G^{1/2} + Q_0 L^{1/2}) \frac{\bar{\epsilon}_n}{\left[1 - \left(\frac{\lambda n}{2h}\right)^2\right]^{1/2}}, \tag{86}$$

where $\bar{\epsilon}_0 = 1$, $\bar{\epsilon}_n = 2 (n \neq 0)$ and

$$Q_0 \cong \frac{N_1 + N_2 \tanh\left[i2\pi N_1 d/\lambda\right]}{N_2 + N_1 \tanh\left[i2\pi N_1 d/\lambda\right]}. \tag{87}$$

and $N_1 \cong e^{-i\pi/4}/\sqrt{L_1}$ and $N_2 \cong e^{-i\pi/4}/\sqrt{L_2}$.

The above formula for S_n is particularly suitable for ELF in which case only the zero mode is of any consequence.

The exponential term inside the summation of (81) determines, in the main, the propagation characteristics of the modes. It can be rewritten as follows

$$\left| \exp\left[-i2\pi S_n(\bar{d}/\lambda)\right] \right| = \exp\left[-\frac{2\pi \bar{d}}{h} u_n\right], \tag{88}$$

where $u_n = -\text{Im } S_n(h/\lambda)$, u_n is a dimensionless measure of the attenuation per unit distance, and Im indicates that the imaginary part is to be taken.

Values of u_n ($n=0$, 1, 2 and 3) are plotted (Figs. 21–26, next page) as a function of h/λ, for various values of B ($=L_1\lambda/h = 2\pi c/(\omega_r' h)$) and the ratio d/h. For these results the earth is assumed to be perfectly conducting. This is justified for propagation over sea water [25].

In each figure the solid line corresponds to the sharply-bounded homogeneous ionosphere and the other curves are for the two-layer ionosphere. The ratio of ω_r''/ω_r' is denoted by q and varies from 10^{-1} to 10^3 in each figure. When the height is specified, u_n can be converted to decibels per 1000 km of path length and h/λ can be converted to frequency in kilocycles per second. Such scales are appended in Figs. 21–26 for $h=70$ km where B values of 0.05, 0.1 and 0.2 now correspond to ω_r' values of 5.4, 2.7 and 1.35×10^5, respectively. The two values of d are then 3.5 and 7.0 km. For any other assumed height h, the scales for frequency and attenuation are changed correspondingly.

Some interesting observations can be made from the numerical results. At the higher frequencies (8 to 18 kc) the attenuation rate is determined almost entirely from the electrical properties of the medium between heights h and $h+d$. Physically, this means that the incident energy does not penetrate to the upper medium above $h+d$. On the other hand, at the lower frequencies (less than 3 kc), the attenuation rate is almost entirely controlled by the electrical properties of the upper medium. In this case the incident energy penetrates through the lower medium with negligible loss and the reflection takes place almost wholly at $h+d$.[5]

Experimental data [32] and [7] on the attenuation rates of VLF waves in daytime, indicate that α is about 2 db/1000 km at 10 kc, greater than 10 db between 3 and 4 kc, and again about 2 db at 500 cps. The two-layer model that best fits this data is shown in Figs. 23 and 24, where $\omega_r' = 2.7 \times 10^5$ and either $d=3.5$ km and $q=10$ or $d=7$ km and $q=100$. This removes the first objection to the single boundary homogeneous ionosphere, namely, that the effective value of ω_r was different at the high and low end of the VLF spectrum.

Extensive and reliable experimental data on attenuation rates at frequencies in the range below 1 kc are now available [11] and [23]. This experimental data slightly modifies our present choice of a suggested two-layer model. It should also be pointed out that the effective value of ω_r depends on the earth's magnetic field [27] and it may also depend on the presence of heavy ions.

C. Conclusion

The numerical results presented here for the two-layer model should be useful in interpreting experimental data for attenuation rates of VLF waves in the frequency range from 1 to 20 kc. Until more direct measurements are available for electron densities and collisional frequencies at the lower edge of the ionosphere, it would seem hardly justified to assume a more elaborate model.[6]

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[5] L. N. Lieberman [14] reasons that the higher frequencies (>10 kc) exhibit greater penetration than the lower frequencies. This is not substantiated by the present results.

[6] *Note:* A noteable exception is the recent work of J. Galejs, "ELF waves in the presence of exponential ionospheric conductivity profiles," IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-9, pp. 554–560; November, 1961.

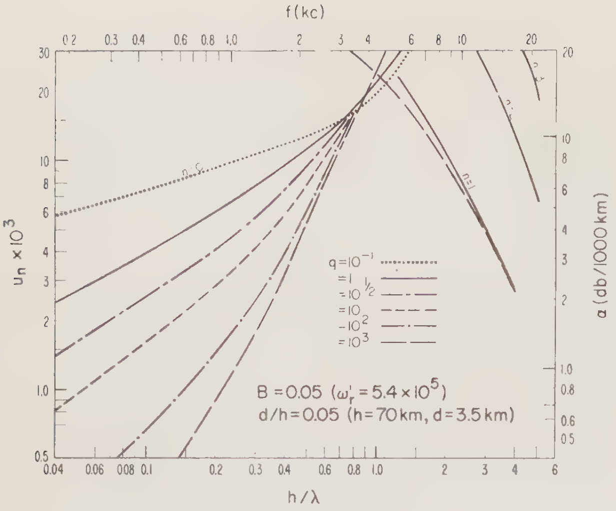

Fig. 21.

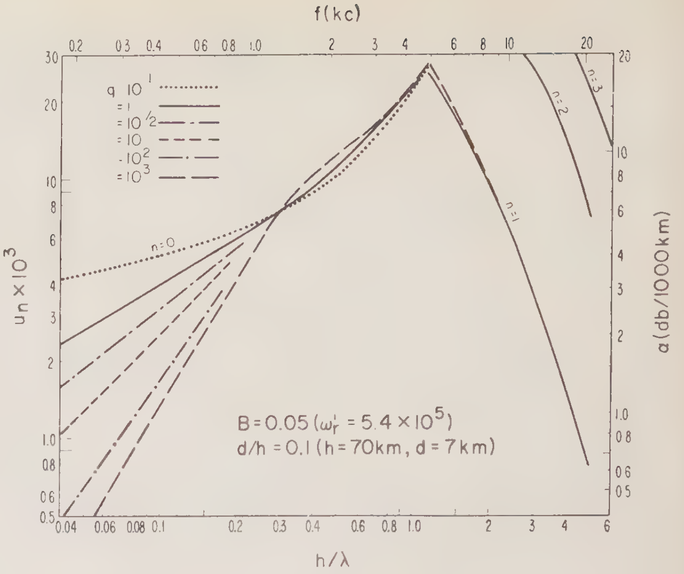

Fig. 22.

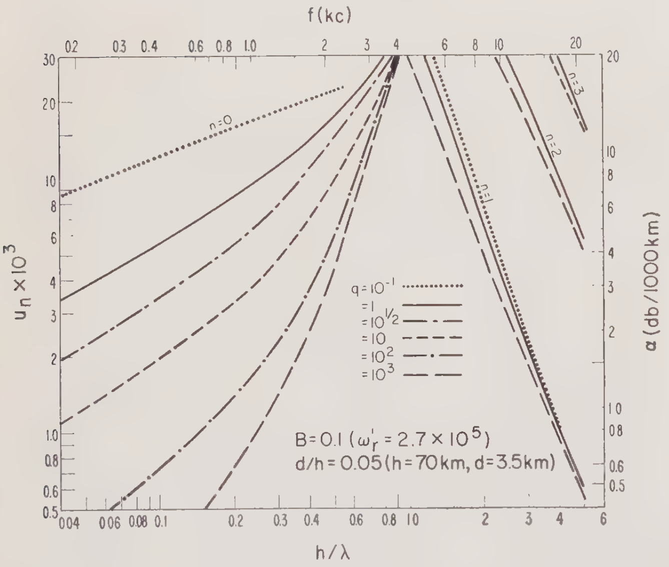

Fig. 23

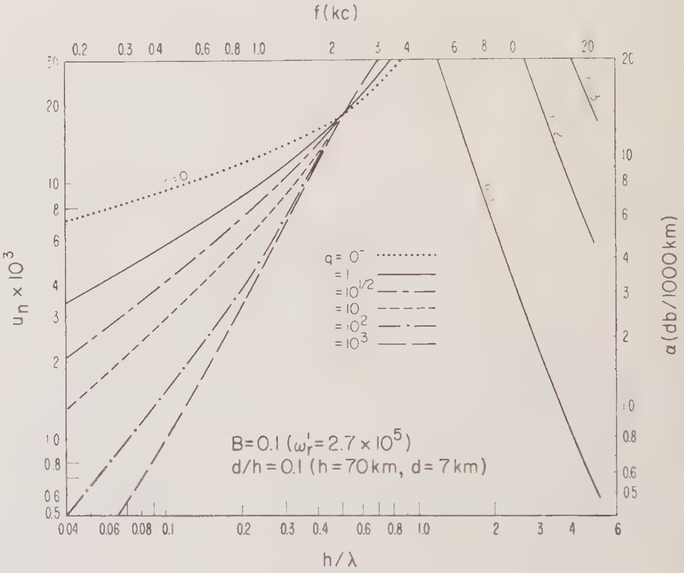

Fig. 24.

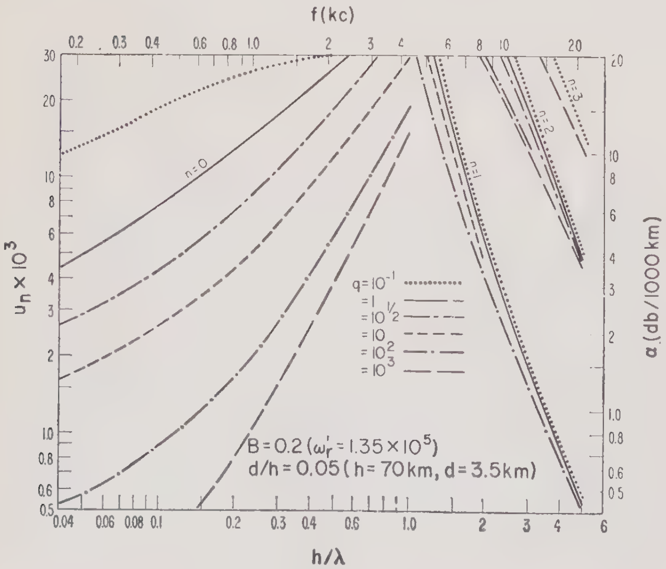

Fig. 25.

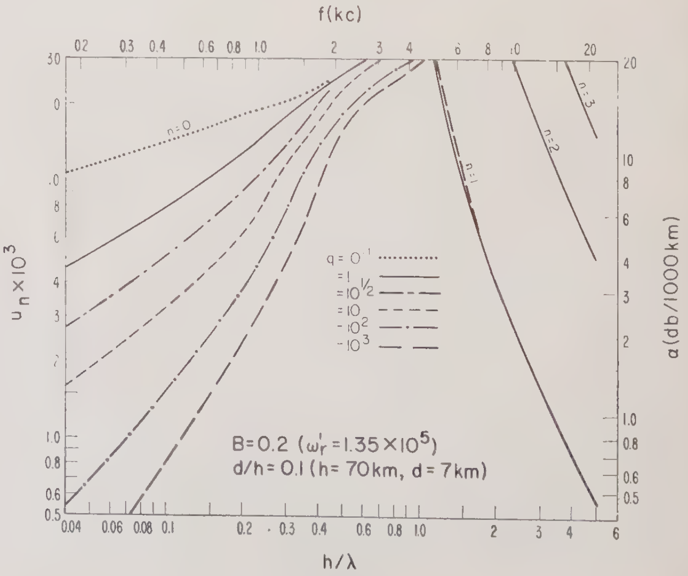

Fig. 26.

ACKNOWLEDGMENT

The author would like to thank Mrs. E. Brackett for her extensive assistance in the preparation of this paper.

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Composite Characteristics of Negative Resistance Devices and Their Application in Digital Circuits*

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Summary—**When a number of negative resistance elements are interconnected, a multistable voltage-current characteristic will be generated. The form of this composite characteristic will depend on the mode of interconnection and on the characteristics of the individual elements. 2^n stable states can be generated using n negative resistance elements when the individual characteristics of the elements obey certain rules derived herein. A modified flip-flop circuit has been developed whose characteristic can be precisely tailored to fulfill the requirements. Several applications to logical functions are discussed. Potential advantages of this method lie in the circuit simplicity resulting from an intrinsic feedback operation which replaces separate logical functions.**

INTRODUCTION

A VARIETY OF negative resistance devices have been made from semiconductors, the most recent being the tunnel diode. The voltage-current relationship of a two-terminal negative resistance element is illustrated in Fig. 1 where x and y are current and voltage or vice versa depending on whether the port is current or voltage driven, respectively. A device having this characteristic could be a bistable element with a low state, arbitrarily chosen to be a "0," for $x \leq x_1$ and a high state, or "1," for $x \geq x_2$. The range $x_1 < x < x_2$ is not counted as a state since it is generally unstable. A characteristic of this type has a multistable range between y_{peak} and y_{valley}. By connecting several such negative resistance devices to a common source one can generate voltage-current composite characteristics of considerable complexity and usefulness.[1–4] A particular case of interest is obtained when the devices have overlapping multistable ranges and are constrained to have the multivalued quantity the same at every instant of time. This paper will describe the properties of these composite characteristics and establish the relationships that the parameters of the individual negative resistance devices must satisfy in order to generate multistate composite curves applicable to various digital functions such as binary addition, scaling to a desired base, analog-digital conversion, etc.

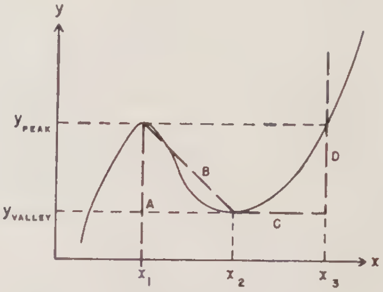

Fig. 1—General form of negative resistance characteristic. x and y represent either current or voltage. The dashed curve is an idealized characteristic.

The accuracy required in some of these applications (like analog-digital conversion) necessitates very carefully controlled current-voltage characteristics of each device. The current-voltage relationships of semiconductor negative resistance elements such as four-layer diodes, tunnel diodes, binistors, point-contact transistors, etc., depends critically on the material of which they are made and on their geometry. This is a severe restriction in generating a precise, predetermined composite characteristic. A means of generating a current controlled negative resistance device that avoids this shortcoming is provided by a modified transistor flip-flop circuit. The voltage-current characteristic of the device can be controlled accurately within wide limits by appropriate choices of circuit parameters. The analysis of the modified flip-flop and the design procedure for the construction of a number of flip-flops to yield a desired composite characteristic is outlined in the Appendix.

GENERATION OF COMPOSITE CHARACTERISTICS

Composite characteristics of engineering interest are obtained from devices having individual characteristics as shown in Fig. 1 when they are constrained to have the same y parameter at all times. This is accomplished when voltage driven devices are connected in series with each other, or when current driven devices are connected in parallel. A great many forms of composite characteristics can result from connecting several devices of the type shown in Fig. 1. It is neither practical

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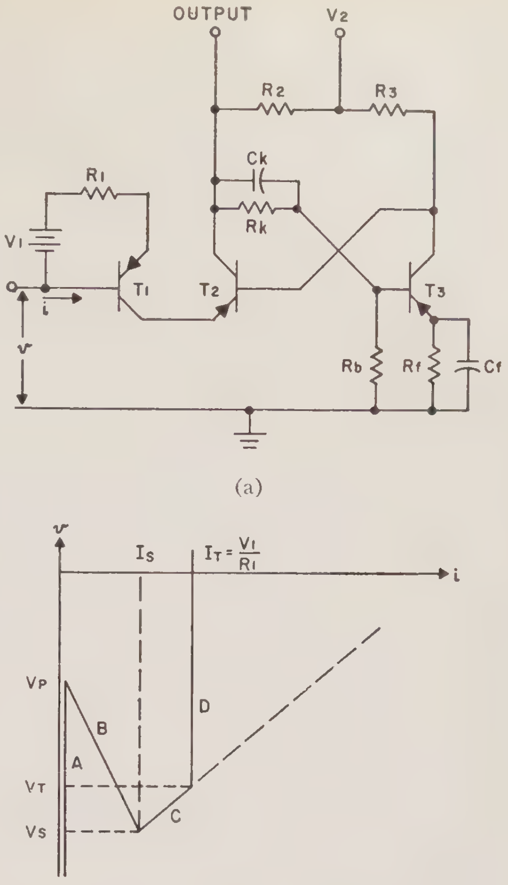
nor fruitful to attempt to define all of them, but rather attention will be focussed on the most interesting combination which can be made from a device approximating the ideal form illustrated by the dashed line in Fig. 1. In some applications[1,2] it is simpler to have a single region approximated by a straight line between (x_2, y_{valley}) and (x_3, y_{peak}) in place of the two regions C and D. It will be seen, however, that since x will not have the constant value x_3 at the values of y_{peak} and y_{valley} of other devices in the series, the single region approximation is not desirable. The departures of the individual characteristics of actual devices from the ideal can then be separately assessed. For instance, the tunnel diode has a broad valley which corresponds to region C and low resistance regions corresponding to regions A and D. The *p-n-p-n* diode offers regions, A, B and C, and a subsidiary current limiting circuit could be added to form region D. A key limitation to the composite use of these devices is really the poor control on (x_3-x_1) for the tunnel diode and the poor control on $(y_{\text{peak}}-y_{\text{valley}})$ for the *p-n-p-n* diode.

A two-terminal negative resistance characteristic can also be generated from a more elaborate circuit utilizing active elements. A case in point is the symmetrical transistor flip-flop which has been analyzed as a negative resistance by Suran and Reibert.[5] From this the circuit of Fig. 2(a) has been evolved, having the characteristic shown in Fig. 2(b). This characteristic differs from that of the idealized curve of Fig. 1 only in that region *C* has a finite resistance instead of zero. In the circuit of Fig. 2(a), transistors $T2$ and $T3$ form the flip-flop. Regions A, B and C correspond to $T2$ cut off, active and saturated, respectively. The high impedance region D is due to the current control circuit of transistor $T1$. Voltage V_1 and resistance R_1 determine the emitter current I_T of $T1$. For collector currents less than I_T, $T1$ is saturated and there is only a small base-collector voltage drop. As the input current approaches the emitter current, $T1$ is pulled out of saturation and a base-collector voltage increases. Thus region D exhibits the output impedance of $T1$ operating in the common base configuration. The voltage-current characteristic of Fig. 2(b) is not determined by the active device but can be tailored within wide limits by the choice of circuit components R_2, R_3, R_k, R_b and R_f, while V_1 and R_1 select I_T. A circuit analysis that outlines the design procedure for determining the circuit components to yield a desired characteristic is presented in the Appendix.



(a)

(b)

Fig. 2—(a) Modified flip-flop circuit. (b) Its voltage-current characteristic.

Static Characteristics of Two Elements

A very useful and most efficient composite characteristic can be evolved with negative resistance characteristics that have progressively overlapping double valued ranges. To illustrate this point consider the voltage-circuit characteristic which results from the parallel connection of two flip-flops that satisfy the set of relationships

$$V_{P2} > V_{P1}$$
$$V_{T2} < V_{S1}$$
$$I_{T2} > I_{T1}$$

using the notation of Fig. 2(b). In the following discussion the binary symbol 0 refers to region A of the flip-flop, while 1 refers to region C or D. When giving a pair of binary digits the digit to the left will refer to flip-flop suffix 2 (the more significant digit) and the digit to the right will refer to flip-flop suffix 1. Later, as more flip-flops are combined, this sequence will be preserved, with the least significant bit to the extreme right. Fig. 3(a) shows the individual flip-flop characteristics and Fig. 3(b) their composite characteristic. This is arrived at in the following way. The system is driven from a current source and when the input current is zero the voltage must fall below V_{P1} with both flip-flops in their A region. This gives the region *ab* of Fig. 3(b) a binary representation of 00. As the applied current is increased, V_{P1} is immediately achieved, flip-flop 1 moves into its negative resistance region causing the voltage to decrease. Since V_{P2} has not been reached, flip-flop 2 is constrained to remain in its zero state while path *bcd* is traced. As the current is further increased, the voltage across the flip-flops increases until V_{P2} is established at point *e*. The binary representation of region *cde* is 10. Increasing the current beyond point *e* causes flip-flop 2 to carry current and move into its negative resistance region. It follows path *ef* until V_{T1} is reached. The system now switches to point *k* for an infinitesimal current increase via the "virtual" path *fghjk*. Path *fghjk* is the unique path from *f* to *k* having the property of identical voltage across the flip-flops at all points. However, over this path the current is always less than it is at *f*. It is clear then that in the switching process the excess current must be taken up by a storage element, in this case the shunt capacitance of the system. The important switching which occurs here is the return of flip-flop 1 to the 0 state. This has been forced to occur because the valley voltage of flip-flop 2 only has a single value, in the low state, of flip-flop 1. A further current increase now gives region *klm* whose binary representation is 10, until *m* is reached at voltage V_{P1}. Now flip-flop 1 again starts to take up current and path *mnop* is traced, of which region *nop* has the binary state 11.

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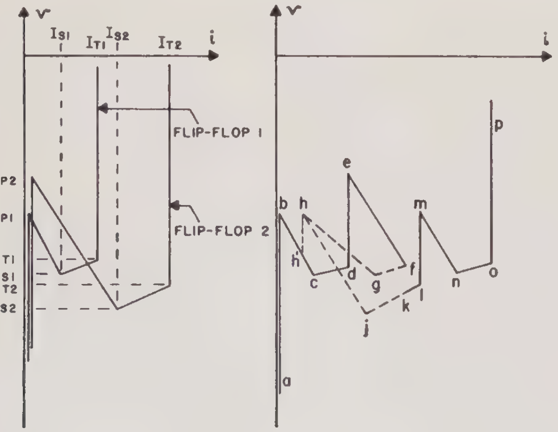
A number of features of this composite curve should be noted. First of all there is an irreversible effect present. The argument given in deriving this curve considered only the case of the current increasing, but when the process is reversed the path traced in coming back will be *ponmljhh'ba*. Observe that now the binary state 01 will be missing. A corollary is that it is not possible to arrive at states in region *fgh*. These states do exist, each flip-flop could be biased from separate sources to the appropriate point and then the parallel connection made. But if the flip-flops are initially connected outside region *fgh*, this region becomes inaccessible.

For the case where I_{T2} is chosen equal to I_{T1}, point *m* falls exactly below point *e* and the resulting composite characteristic is the current driven analog of the balanced pair of tunnel diodes.[4] Nominally balanced tunnel diode pairs have identical peaks and valleys, but that is not achieved in practice. In the particular case selected here, flip-flop 1 would assume the 1 state approached from either side, but if the conditions were modified to $V_{S1} < V_{S2}$, then flip-flop 1 would assume the 1 state when approached from below, but flip-flop 2 would retain the 1 state when approached from above. Thus small differences in the peaks and valleys of a balanced pair set a preference for one tunnel diode rather than the other to reside in the 1 state when approached from a particular direction. This in turn sets a lower limit to the net current which must be fed to a balanced pair to decide its state.



(a) (b)

Fig. 3—(a) Two flip-flop characteristics. (b) Their composite characteristic.

Dynamic Considerations

It must be stressed that only the static characteristic has been described so far. The argument is essentially unchanged when current variations occur at speeds which do not effectively change the static characteristics, *i.e.*, speeds well below the switching speed of the device. At speeds above the switching speed the negative resistance characteristic no longer exists (this is analogous to the statement for tunnel diodes, that they do not exhibit negative resistance above their cutoff frequency). This can have a serious effect on the resulting state when the driving parameter is changed rapidly compared to the switching speed of the devices. Thus the argument given for which tunnel diode of a balanced pair tends to achieve the 1 state when approached from a particular direction might readily change if the approach is made rapidly and the switching speed of the two tunnel diodes is different. One cannot make general statements about this effect, which must be considered for each device separately. One way in which this effect may be reduced when a particular switching sequence is desired is to make the separations between successive peaks and valleys larger. The dynamic modifications of the static characteristic will then have to be proportionately greater before the preselected order of the peaks and valleys has been altered. On the other hand this reduces the number of devices having a given breakdown voltage that can be connected together in this way.

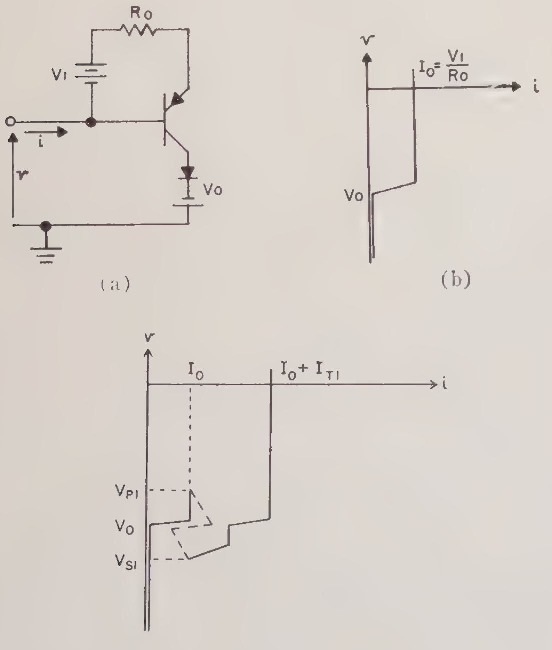
When point *j* occurs at a current value of I_{T1}, *i.e.*, $I_{S2}=I_{T1}$, and the negative resistance region of flip-flop 2 is made unstable, the operating point of the system will switch directly from *e* to *j* as the current is infinitesimally increased from below to above I_{T1} and vice versa. In this way region 01 will switch directly into 10. For $I_{S2}<I_{T1}$ switching from 01 to 10 will occur at I_{T1} but switching from 10 to 01 will not occur until the current is reduced below I_{S2}. In a system with more flip-flops the appropriate inequality can readily become large enough to miss several binary states in the reverse direction. It is to be noted that it may be problematic to make a negative resistance region unstable. Tunnel diodes have inherently unstable negative resistance regions below

their cutoff frequency. The modified flip-flop under discussion has a stable negative resistance region and capacitance has been added to the system to make it unstable. Capacitors are added both in parallel with resistance R_f of Fig. 2 and in parallel with the input terminals. One effect of these capacitors is to cause dynamic peak and valley voltages which overshoot the static range. As a result care must be taken that the overshoot does not overlap another flip-flop and cause an unwanted switching.

Characteristics of n Elements

Before extending these results to more flip-flops it is desirable to eliminate the remaining ambiguous regions *ab* and *mn*. The circuit of Fig. 4(a) having the characteristic of Fig. 4(b) when combined in parallel with flip-flop 1 yields the composite curve of Fig. 4(c). This was obtained in a similar manner to that of Fig. 3(b). The dashed line in Fig. 4(c) is the negative resistance region of the flip-flop and is unstable. The parameters satisfy $V_{P1} > V_0 > V_{T1}$ and $I_0 = I_{S1}$, thus giving a bistable characteristic in which the 0 region leads directly into the 1 region. The conditions leading to a two bit binary circuit in which the binary regions follow successively and reversibly can now be summarized (notation of Figs. 3 and 4):

1) Negative resistance regions of the flip-flops be unstable
2) Circuit of Fig. 4(a) incorporated
3) $V_{P2} > V_{P1} > V_0$
4) $V_{T2} < V_{S1}$; $V_{T1} < V_0$
5) $I_{S1} = I_0$; $I_{S2} = I_0 + I_{T1}$.



(a) (b)

(c)

Fig. 4—(a) Additional positive resistance circuit. (b) Its *v-i* characteristic. (c) Composite characteristic of this circuit with flip-flop 1 of Fig. 3(a).

Table I shows the current ranges of the four binary regions from which it is seen that the 01, 10 and 11 regions will all be equally spaced if $I_{T2} = 2I_{T1}$. State 00 can be made half of state 01 by choosing $I_{T1} = 2I_0$.

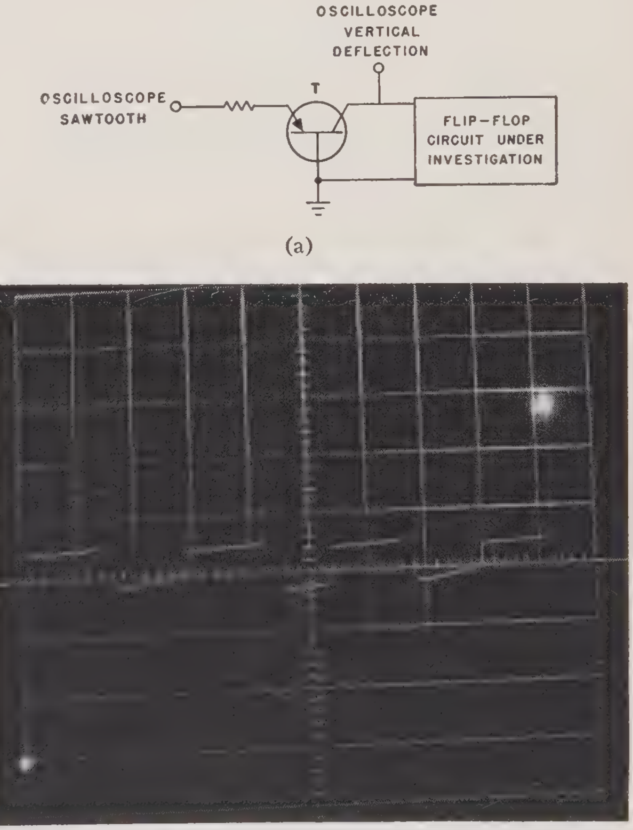
An experimental confirmation using the circuit of Fig. 5(a) has yielded the composite characteristic oscilloscope trace of Fig. 5(b). The emitter of transistor T is driven from the sawtooth output of the oscilloscope. This input to the system is equivalent to a current source where the current to the flip-flops is directly proportional to the horizontal distance of the oscilloscope beam from its origin. The horizontal trace of the oscilloscope thus represents the current axis while the vertical input gives the voltage.

When more flip-flops are added, conditions 3, 4 and 5 are readily generalized to

6) $$V_{Pn} > V_{P(n-1)} \cdots > V_0.$$

TABLE I

From	To	Binary State	
0	I_0	0	0
I_0	$I_{T1}+I_0$	0	1
$I_{T1}+I_0$	$I_{T2}+I_0$	1	0
$I_{T2}+I_0$	$I_{T2}+I_{T1}+I_0$	1	1


OSCILLOSCOPE VERTICAL DEFLECTION
T
OSCILLOSCOPE SAWTOOTH
FLIP-FLOP CIRCUIT UNDER INVESTIGATION

(a)

(b)

Fig. 5—(a) Circuit used to display flip-flop characteristics. (b) Oscilloscope trace of composite of two flip-flops and additional circuit. Horizontal scale is 0.13 ma/cm and vertical scale is 2 v/cm.

This condition states that a particular flip-flop cannot switch to its 1 state until all the lower-order flip-flops are in their 1 state.

7) $V_{Tn} < V_{S(n-1)}; \quad \cdots V_{T1} < V_0.$

When a flip-flop switches to its 1 state it obviously must pass through its valley. Then condition 7 ensures that it will cause all lower-order flip-flops (which must be in the 1 state from 6) to return to the 0 state.

8) $$I_{Sn} = I_0 + \sum_{m=1}^{n-1} I_{Tm}.$$

This condition ensures that for any given current input there is one and only one stable setting (no flip-flops in their negative resistance region) of the states, 0 or 1, of the various flip-flops.

If it is desired that the binary regions have equal ranges, one requires in addition that

9) $I_{Tm} = 2^{m-1} I_{T1} \quad \text{for } m = 2 \text{ to } n.$

Note that since I_{Tn} is greater than I_{Sn} [see Fig. 2(b)] condition 5 implies that

10) $$I_{Tn} > I_0 + \sum_{1}^{n-1} I_{Tm}.$$

Condition 10 must be fulfilled for all binary states to appear. If this condition is not fulfilled some states will be hidden behind others. One such instance, the current driven analog of the balanced pair of tunnel diodes, has been discussed. As will be shown below, this condition limits the number of tunnel diodes which can be combined to generate a multistate composite curve with no binary states missing.

Condition 8 can be relaxed in two ways, each having different consequences.

a) $$I_{Sn} > I_0 + \sum_{1}^{n-1} I_{Tm}.$$

There will be certain current ranges in which at least one flip-flop will be undergoing astable multivibration. These will be ambiguous ranges to which no unique binary code can be assigned.

b) $$I_{Sn} < I_0 + \sum_{1}^{n-1} I_{Tm}.$$

In this case the composite characteristic becomes irreversible. However, it still maintains correct binary form for monotonically increasing inputs.

In certain applications the disadvantage of these consequences may be outweighed by the advantage of less critical design. Fig. 6 shows an oscilloscope trace for five flip-flops connected together. The two lowest flip-flops are designed to fulfill condition 4 exactly while the upper three are relaxed to case b above, choosing I_{Sn} about two thirds of I_{Tn}. Again the driving current used to display this trace is derived from the sawtooth output of the oscilloscope. The trace is therefore the characteristic resulting from an increasing current input only.

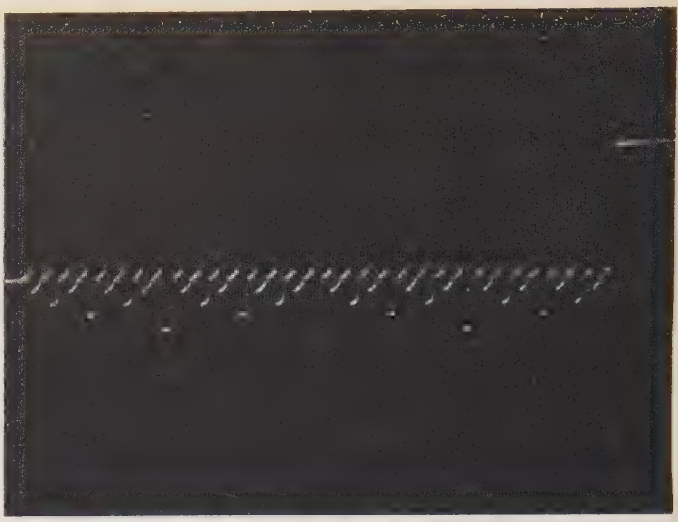


Fig. 6—Oscilloscope trace for five flip-flops. Horizontal scale is 1.25 ma/cm and vertical scale is 5 v/cm.

This treatment has now derived the maximum number of distinguishable positive regions derived from n negative resistance devices. It remains to determine how relaxing certain of the conditions needed to achieve this maximum will change the number of regions actually available. The special case already cited, the balanced pair of tunnel diodes, demonstrated that combinations of nominally identical units result in one region being hidden behind another. When this is generalized to n identical devices the resulting number of regions will have the minimum value of $(n+1)$. The actual details of which device is in its 1 state in any particular region will depend on differences which exist between the peak and valley values of the devices. $(n+1)$ regions have resulted from relaxing the equivalent of condition 10 to allow the quantity $(x_3 - x_1)$ of Fig. 1 to be the same for all devices. Another way to reduce the number of regions available retains condition 10 and modifies the order of the inequalities of condition 6 and/or 7. With the aid of the rules developed here, appropriate choices can be made in altering conditions 6, 7 and 10 either singly or together to achieve any desired number of positive resistance regions between $(n+1)$ and 2^n from n devices.

It has been indicated earlier that similar arguments can be applied to tunnel diodes but that an analogous requirement to condition 10 limits the number of tunnel diodes which can be combined. This follows because there is a physical limit to the value V_3, corresponding to x_3 in Fig. 1, that a tunnel diode can have. This voltage is related to the band gap of the semiconductor from which the tunnel diode is made. Of existing tunnel diodes the largest value of V_3 is about 1.1 volts for GaAs and the smallest about 0.5 volt for Ge. However, a germanium tunnel diode can have its value of V_3 effectively reduced to 0.3 volt by shunting it with diodes.

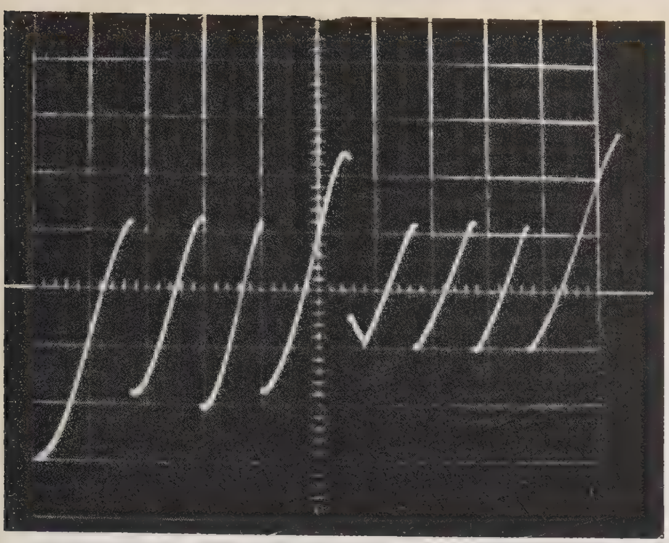


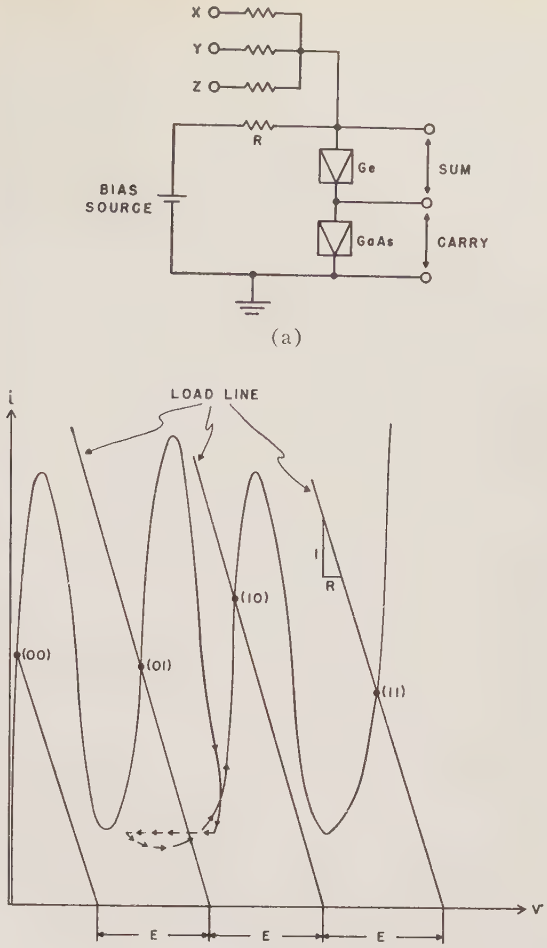
Fig. 7—Oscilloscope trace of the composite characteristic of three tunnel diodes. Horizontal scale is 0.2 v/cm and vertical scale is 1 ma/cm.

This allows condition 9 to be fulfilled by three tunnel diodes, one Ge shunted with diodes, one unshunted Ge and one GaAs. Fig. 7 shows an oscilloscope trace of the composite characteristic derived from three such tunnel diodes. Again, the source is derived from an oscilloscope sawtooth output and only the characteristic for increasing voltage is shown. Another GaAs tunnel diode can be added in series to these three, having a higher peak current than the others and a valley current below the two Ge tunnel diodes but above the first GaAs tunnel diode. This will increase the number of states available from eight to twelve.

APPLICATIONS

The multistate composite curves generated as described can be used to fulfill a variety of digital functions with a low number of components. Some of these applications have been implemented in the laboratory and will be discussed briefly. In some cases the digital function can be best achieved with current controlled devices while others employ voltage controlled devices. The choice between them is made on the basis of the suitability of the particular devices to the specific problem at hand. A number of common digital operations that illustrate these techniques will now be described.

Full Binary Adder: Stated briefly, a full binary adder receives signals representing a 1 or 0 from three different sources, and delivers a two bit binary output 00, 01, 10 or 11 depending whether none, one, two or all three input signals, respectively, are 1. In this binary output the left-hand bit is the Carry output and the right-hand bit is the Sum. Fig. 8(a) shows a circuit of two tunnel diodes connected in series, with three inputs X, Y and Z and two outputs Sum and Carry. The germanium tunnel diode has a lower peak current and a higher minimum valley current than the gallium arsenide tunnel diode. Since they are connected in series they give rise to the composite characteristic shown in Fig. 8(b). The input signals impressed on the system at X, Y and Z are assumed to be from a zero voltage source when the input is a 0 and a fixed voltage V when the input is a 1. The diodes are biased from a constant voltage source through a low resistance R. In this circuit configuration the diodes see a constant load as represented in Fig. 8(b) by the load lines R. The variable is the voltage presented which will be different for the four cases, none, one, two and three inputs present. Thus it is required that the space E between the successive load lines is equal in all cases, accomplished by an appropriate choice of V. The Carry is obtained across the gallium arsenide tunnel diode and the Sum across the germanium tunnel diode (in order to cascade these outputs to other stages, the state of the tunnel diode must be sensed with further circuits designed for their specific purpose.) A full adder that uses the current driven analog of this principle has been constructed with p-n-p-n diodes by Horton and Anderson.[2]



(a)

(b)

Fig. 8—(a) Two-tunnel diode full binary adder. (b) Composite characteristic of the two tunnel diodes and appropriate load lines for 0, 1, 2 and 3 inputs.

Analog-to-Digital Encoders: The full binary adder which has just been described becomes a two bit analog-to-digital converter when powered from a single source rather than three separate inputs as required for the adder. The single source represents a specific load to the tunnel diodes, and the operating point achieved will depend on the source voltage. The system can be extended to three bits using three tunnel diodes having the characteristic of Fig. 7. Unfortunately it is not possible to extend the resolution of the encoder beyond three bits with presently available tunnel diodes.

A system well suited to analog-to-digital encoding operations is the series of flip-flops. A linear five bit system is readily made utilizing the characteristic of Fig. 6. The analog input voltage is sampled and stored in a hold capacitor. The sampling switch is open during the encoding operation and pulse stretching is achieved by the high input impedance amplifier, designed to allow insignificant droop during the encoding operation. The output of the amplifier feeds a grounded base transistor which transforms the voltage pulse to a corresponding current pulse. Readout of the digitalized representation is done in parallel on all flip-flops after the system has been allowed to find its equilibrium state. A more detailed description of the subsidiary circuitry required for such a system will be presented in a separate paper elsewhere.

Counting to a Desired Base: The function of a counter is to receive a succession of input pulses. As each pulse arrives it causes the system to change its state. Between pulses the system holds its new state until it is moved to a higher state. When the nth pulse of a counter to the base n arrives, it is made to trigger a reset which returns the counter to zero, and at the same time delivers a carry output. The series connected tunnel diodes having the composite characteristic of Fig. 7 can be biased from a constant current source I_0 lying between the lowest peak and the highest valley current, *i.e.*, $I_{V1} < I_0 < I_{P1}$. This gives rise to the eight stable operating points. In order that the stable operating points be reached successively it is necessary to trigger the counter from a low impedance source. The output of the counter is available in two forms. The voltage across the tunnel diode string will be a staircase with increments of about 0.3 volt for each pulse received. Binary output is available by sensing the voltages across the individual tunnel diodes.

Counting to a lower base than eight is readily achieved by an appropriate setting of the voltage value at which the reset circuit is triggered. A smaller number of input pulses will then yield a carry output and reset. A higher base than eight is available only if more stable states are generated. A scale of ten counter has been constructed[6] by choosing four tunnel diodes satisfying conditions that yield a composite characteristic having ten stable states.

One application of some importance, subharmonic generation, follows directly from the operation of counting to a desired base n. Each cycle of the input frequency source is transformed (if necessary) to form the input pulse to the counter. The carry pulse thus appears once for every n cycles of the input signal. The carry output is sent through a low-pass filter with a cutoff frequency slightly above $1/n$ of the input frequency, at the output of which only the $1/n$th subharmonic frequency will be present.

CONCLUSIONS

By interconnecting a number of elements, each having a negative resistance region, one can generate a great variety of multistable voltage-current characteristics. It may be considered that these characteristics are derived from a feedback operation. The feedback path is the interconnection between the elements which forces the switching of one element to control the switching of others. In this way a number of conventional logical operations are replaced by a feedback decision-making operation which sets the final state that the bistable elements assume for a given input. While in principle this technique can be extended to any number of elements, in practice it is limited in most semiconductor devices by the material and the fabrication process. A rather different approach in obtaining a negative resistance characteristic has been described, where a flip-flop can be made to display a negative resistance determined by the choice of its circuit parameters. This therefore leads to increased flexibility in the process of generating multistable characteristics. These multistable characteristics have very useful applications in implementing logical and arithmetic functions, several of which have been discussed in some detail.

APPENDIX

This is an approximate analysis of the modified flip-flop circuit based on the following assumptions: 1) the base-emitter voltage drop is neglected and 2) the α of the transistor is taken to be unity, *i.e.*, the base current is ignored and the collector current is equal to the emitter current. The approximations simplify the design procedure and lead to results close to actual conditions. The negative resistance region can be defined by its two end points: voltage V_P and zero current when transistor $T2$ of Fig. 2 is just cut off, voltage V_S and current I_S when $T2$ is on the edge of saturation.

Calculating Point (V_P, 0): Transistor $T2$ is cut off and transistor $T3$ is on. Since $T2$ is just cut off, no current flows into the circuit from it, and under assumption 1 above, the emitter and base are at the same voltage V_P. The base of $T2$ is directly connected to the collector of $T3$ so that the voltage at the collector of $T3$ is V_P. Thus the flip-flop can be represented by the equivalent circuit of Fig. 9(a). Voltage v_1, and currents i_1 and i_2 (in the

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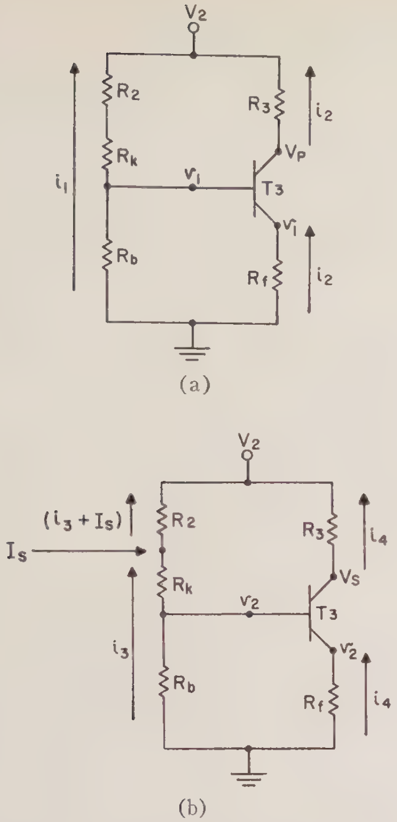
[6] B. Rabinovici and J. Klapper, "Digital Circuits with a Minimum Number of Tunnel Diodes," presented at NEREM, Boston, Mass., 1961.



(a)

(b)

Fig. 9—Equivalent circuit of the flip-flop used to calculate the points (a) V_P, 0; (b) V_S, I_S.

sense shown) are also defined in Fig. 9(a). One can readily now write

$$v_1 = \frac{V_2 R_b}{R_2 + R_b + R_k} \tag{1}$$

$$-v_1 = i_2 R_f \tag{2}$$

$$V_P - V_2 = i_2 R_3. \tag{3}$$

Eliminating i_2 and v_1 between these equations one obtains

$$V_P = V_2\left(1 - \frac{R_b R_3}{R_f(R_2 + R_b + R_k)}\right). \tag{4}$$

It is assumed that $v_1 > V_P$ in order that $T3$ is not saturated. This condition when impressed upon (1) and (2) yields

$$R_f \leq \frac{V_P R_3}{V_2 - V_P}\cdot \tag{5}$$

It can be expected that the flip-flop will most nearly approach the desired condition when R_f is close to this limit, for then v_1 is largest and comes nearest to justifying having ignored the base-emitter voltage drop.

Calculating Point (V_S, I_S): For this case $T2$ is saturated and $T3$ is on. With $T2$ saturated, the emitter, base and collector of $T2$ are at the same voltage V_S. Since $T2$ is only on the edge of saturation, the base current of $T2$ is still taken to be zero, and current I_S flows into the collector of $T2$. This gives the flip-flop equivalent representation shown in Fig. 9(b). Voltage v_2 and currents i_3 and i_4 are defined in Fig. 9(b). One can now write

$$V_S - V_2 = i_4 R_3 \tag{6}$$

$$-v_2 = i_3 R_b = i_4 R_f \tag{7}$$

$$v_2 - V_S = i_3 R_k \tag{8}$$

$$V_S - V_2 = (I_S + i_3) R_2. \tag{9}$$

Eliminating i_3, i_4 and v_2 between (6), (7) and (8) leads to

$$V_S = \frac{V_2}{1 + \dfrac{R_b R_3}{R_f(R_b + R_k)}}\cdot \tag{10}$$

Eliminating i_3 in (9) gives

$$I_S R_2 = -V_2 + V_S\left(1 + \frac{R_2}{R_b + R_k}\right). \tag{11}$$

Let

$$X = \frac{R_f(R_b + R_k)}{R_6 R_3} \tag{12}$$

and

$$Y = \frac{R_f R_2}{R_b R_3}\cdot \tag{13}$$

Eqs. (4) and (10) now become

$$V_P = V_2\left(1 - \frac{1}{X + Y}\right) \tag{14}$$

and

$$V_S = \frac{V_2}{1 + \dfrac{1}{X}}\cdot \tag{15}$$

Eliminating V_S between (11) and (15) and with the aid of definitions (12) and (13) one obtains

$$R_2 = -\frac{V_2}{I_S}\cdot\frac{1 - Y}{1 + X}\cdot \tag{16}$$

Eqs. (12) and (13) can be rearranged in the form

$$X = \frac{V_S}{V_2 - V_S} \tag{17}$$

and

$$Y = \frac{V_2}{V_2 - V_P} - X. \tag{18}$$

V_2, V_P, V_S and I_S are preselected, and so (17) and (18) give X and Y. These are substituted into (16) to give R_2.

For simplicity R_b is chosen equal to R_f. Thus from (12) and (13) one has

$$R_3 = \frac{R_2}{Y} \tag{19}$$

$$R_b + R_k = \frac{X}{Y} \cdot R_2. \tag{20}$$

In summary the design procedure would be as follows:

One chooses V_2, V_P, V_S and I_S. Then from (17) and (18) one obtains the values of X and Y. These and I_S in (16) give R_2. With the aid of (19) and (20) one finds R_3 and (R_b+R_k). Eq. (5) allows selection of R_f, and R_b is chosen equal to R_f. Knowing R_b one now determines R_k.

The design procedure has been used to build and test the required flip-flop. It was found that the experimental results gave good agreement with the characteristics predicted by this approximate analysis. The largest design errors occur for V_P which can be corrected by altering R_3 without affecting V_S and I_S appreciably.

ACKNOWLEDGMENT

The authors wish to thank J. Sie for helpful discussions during the early stages of this work, and H. Sinofsky, who aided the experimental investigations.

Phase-Stable Oscillators for Space Communications, Including the Relationship Between the Phase Noise, the Spectrum, the Short-Term Stability, and the Q of the Oscillator*

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Summary—**Highly phase-stable, crystal-controlled oscillators are playing an increasingly important role in extending the range of deep-space communications. For example, during a recent radar experiment with the planet Venus, then at a range of 35-million miles, real-time detection was accomplished with a receiver bandwidth of 5 cps and a search frequency of 2388 Mc. Spectral measurements of the Venus-reflected signal indicated at times a spectrum of only a few cycles in width. The ability to resolve such narrow phenomena was gained through the use of extremely phase-stable oscillators combined with extremely precise predicted control of the frequency of the receiver local oscillator. The purpose here is to discuss oscillator phase noise, its origin, and techniques for its observation and measurement. Relationship between the phase noise, the spectrum, the short-term stability, and the Q of the oscillator is established.**

I. INTRODUCTION

SINCE THE ORIGINAL work of Cady and Pierce in the early 1920's, an ever growing volume of material has been published on crystal oscillators and means for stabilization. However, very little has appeared on the subject of phase instability because of the difficulty in observing and measuring the phenomenon.

No oscillator has yet been discovered that is irrefragably stable. Consequently, all oscillators will have orderly noise spectra organized in accordance with well-established laws of noise and probability[1,2] thus permitting the stability of an oscillator to be com-

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† Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif.

[1] W. A. Edson, "Noise in oscillators," PROC. IRE, vol. 48, pp. 1454–1466; August, 1960.

[2] J. A. Mullen, "Background noise in nonlinear oscillators," PROC. IRE, vol. 48, pp. 1467–1473; August, 1960.

pletely defined by its noise spectra. A distinction must be made between the noise-power spectrum produced by FM or AM and the phase-noise spectrum,[2] which will be discussed later. Extremely stable oscillators will have extremely narrow noise-power spectrums which, for highly stable frequency standards, may be only a few hundredths of a cycle wide. The representation of an oscillator spectrum as a delta or line function surrounded by extremely low-order sidebands is an illusion created by the inadequacies of most spectrum analyzers.

In the measurement of oscillator stability, instrumentation limitations, particularly at radio frequencies, require the use of a reference or comparison oscillator. This oscillator may either be an ideal oscillator or an oscillator having precisely the same or known stability characteristics. Ideal in this application would be an oscillator more stable by at least an order of magnitude. Frequency multipliers may be used to multiply the FM noise spectrum width for improved resolution. The spectrum will widen with multiplication in accordance with the established laws of PM or FM modulation. The frequency multiplier operates like a microscope, and like the optical objective the magnification will depend on the quality of the multiplier. However, multiplications of the order of ×1000 are well within the scope of present-day technology, even up to microwave frequencies. In addition, the increasing availability of computer facilities has expedited the application of Fourier transform techniques[3] to extremely narrow-band spectrum analysis.

II. PHASE STABILITY AND SYSTEMS SPECIFICATIONS

Phase-coherent or synchronous space communication systems[4] have stressed the need for more clearly defining and measuring the random phase stability of oscillators. Such systems, using crystal-oscillator-multiplied frequencies up to the UHF and microwave band, have provided an invaluable tool for phase-noise study and observation. Phase coherence in a space system is ensured by automatically tracking the Doppler component with a servo-loop that defines the system bandwidth. The stability of the local oscillators is then specified in terms of the rms phase noise and the system bandwidth. The rms phase noise is measured at the detector output terminals with a high-level input signal to the receiver. As will be shown later, an inverse function related to the phase spectrum causes the oscillator phase-noise in a closed-loop receiver to increase rapidly as the bandwidth is reduced.

For a nonsynchronous or open-loop space communication system,[5] in which the receiver tuning may be maintained by predicted control of the oscillator, the local oscillator stability must now be specified in terms of the width of the power spectrum. The system is no longer sensitive to phase disturbances and responds only to noise-power fluctuations.

These specifications are intimately related to the short-term frequency stability and the Q of the oscillator resonator. It will be shown that the short-term frequency stability is, in turn, directly related to thermal noise in the oscillator. In the discussion, specific reference is made to highly stable voltage-controlled VHF crystal oscillators of the type used for space communications, where the Doppler component must be compensated by tuning the oscillator and where the short-term stability requirement, depending on the application, ranges from 1 pt/10^7 to 1 pt/10^{10} or greater.

III. OSCILLATOR PHASE STABILITY AND ITS RELATION TO RESONATOR Q

A block diagram representation for a VHF voltage-controlled crystal oscillator (VCO) is shown in Fig. 1. The element k is a single-stage transistorized amplifier operating in the 30-Mc region. The amplifier is bias-controlled by the amplitude of the oscillation, thus making the gain k a function of the voltage input. The thermal-noise voltage present at the amplifier input terminals is represented by the generator e_N. The feedback element β will include a phase-control network and a crystal resonator having a typical unloaded Q of 100,000; the collector-tank circuit Q will be less than 100. A variable dc voltage E_c applied to the phase-control network controls the frequency of the oscillations.

The gain of a linear loop may be expressed as follows:

$$K = \frac{k}{|1 - k\beta|}.$$

As $k\beta$ approaches unity the gain rapidly increases. In particular, the Barkhausen criterion states that when $k\beta = 1$, steady-state oscillations occur. However, in practice, as oscillations build up k approaches unity, $k\beta$ becomes fractionally less than unity, and K assumes some finite value. The criterion may also be expressed in polar form,[6] $1/ke^{j\theta} = \beta e^{j(\phi+\pi)}$, where $1/k = \beta$ represents magnitude equilibrium and $\theta = (\phi + \pi)$ represents angular equilibrium. The quantities θ and ϕ are the phase angles associated with the coupling networks, so that to meet the angular criterion of oscillation, $(\theta - \phi) = \pi$, which assumes that the oscillator is a linear harmonic oscillator and that the waveform is perfectly sinusoidal.

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[3] R. B. Blackman and J. W. Tukey, "The Measurement of Power Spectra," Dover Publications, Inc., New York, N. Y.; 1958.

[4] M. H. Brockman, H. R. Buchanan, R. L. Choate, and L. R. Malling, "Extra-terrestrial radio tracking and communication," PROC. IRE, vol. 48, pp. 643–654; April, 1960.

[5] One of the receiver systems used for the Venus experiment. See L. R. Malling and S. W. Golomb, "Radar measurements of the planet Venus," *J. Brit. IRE*, vol. 22, pp. 297–303; October, 1961.

[6] T. S. Gray, "Applied Electronics," John Wiley and Sons, Inc., New York, N. Y., ch. 11; 1957.

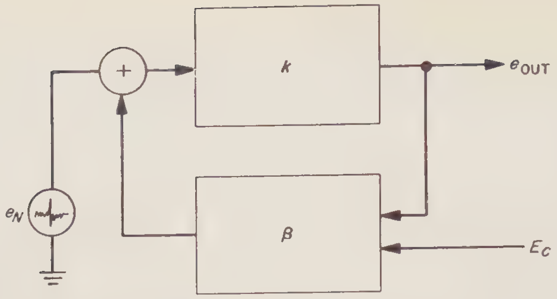

Fig. 1—Basic diagram of voltage-controlled local oscillator.

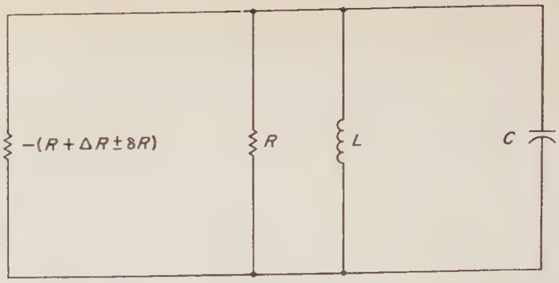

Fig. 3—Negative-resistance oscillator equivalent of feed-back oscillator.

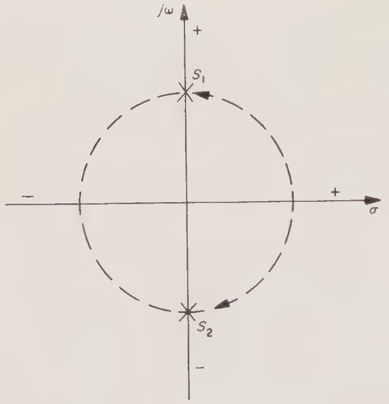

Fig. 2—Pole positions for steady-state oscillations.

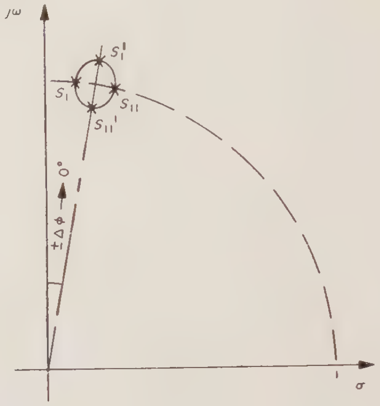

Fig. 4—Incremental variations in pole position with noise in oscillator.

In this case the input and output waveforms are completely phase-coherent.

It is informative to consider two conditions of operation, 1) an initial turn-on transient period where noise initiates the oscillation, and 2) steady-state oscillation where noise is still present, and to establish their relationship to the poles of the impedance function. The poles of the impedance function of a linear system represent the amplitude and frequency of the rotating vector in the time domain. With turn-on, oscillations may be assumed to be initiated by the noise generator; at this time the poles are in the positive region and the amplifier gain is high. The oscillations are now exponentially increasing. Automatic gain control and amplifier nonlinearities cause k to decrease; the poles S_1S_2 move to the $j\omega$ axis as indicated in Fig. 2, and steady-state oscillations are established.

The precise pole positions with steady-state oscillation established but with noise still present are more clearly indicated by circuit analysis. The amplifier and the feedback network of Fig. 1 may be transformed into an equivalent negative-resistance oscillator[7] as shown in Fig. 3. A negative-resistance element $(R+\Delta R\pm\delta R)$ is introduced that is fractionally larger than R, the sum of the positive resistances in the circuit, to ensure continuous oscillations. This configuration permits the noise to be represented as a random variation $\pm\delta R$ in the negative resistance. The poles of the response transform for the negative-resistance oscillator may now be expressed as follows:

$$S_{1,2} = -\frac{1}{2C}\,\frac{(\Delta R \pm \delta R)}{R^2} \pm j\sqrt{\frac{1}{LC} - \frac{1}{(2C)^2}\left(\frac{\Delta R \pm \delta R}{R^2}\right)^2}.$$

To meet the Barkhausen criterion, $(\Delta R\pm\delta R)$ must become zero, making the oscillator frequency $\omega_0=\sqrt{1/LC}$. However, the presence of the noise-component $\pm\delta R$, which includes all circuit perturbations, requires that a small negative-resistance component ΔR be present at all times to ensure sustained oscillations. As the equation indicates, perturbations $\pm\delta R$ in ΔR create both frequency and amplitude jitter with a corresponding jitter in S_1 and S_2. The oscillator thus settles in a position of unbalanced equilibrum, as shown by the pole positions $S_1S_{11}S_1'S_{11}'$ in Fig. 4, where the angle between the $j\omega$ axis and the mean pole position $\Delta\phi\rightarrow 0°$, and the jitter is represented to a greatly enlarged scale. Corresponding pole positions representing the amplitude and frequency jitter will also appear at S_2. Like the cyclist who must continually apply correction signals to the handlebars to maintain balance, the oscillator must continually apply correction signals to maintain equilibrium.

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[7] T. L. Martin, Jr., "Electronic Circuits," Prentice-Hall, Inc., Englewood Cliffs, N. J., ch. 10; 1955.

The precise phase relationship in the feedback loop is established by the phase-vs-frequency resonance characteristic of the crystal. After the initial turn-on, the crystal will automatically adjust phase until the frequency of oscillation complies with the Barkhausen criterion, *i.e.*, when $(\theta-\phi)=\pi$. For a typical 30-Mc VCO, frequency shifts up to several kilocycles removed from resonance may be required to compensate for the added Doppler component corresponding to a crystal phase deviation of 1 radian or greater. A typical nonsymmetrical characteristic for a third-overtone 30-Mc series-resonant crystal is shown in Fig. 5, where Δf represents an incremental change in the oscillatory frequency.

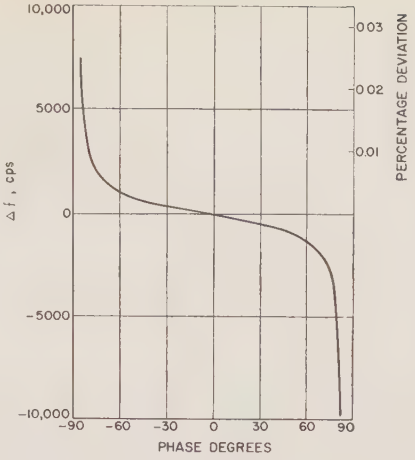

Fig. 5—Phase-vs-frequency characteristics of a 30-Mc crystal resonator.

As the frequency is determined by the phase relationships established in the feedback loop, the frequency stability becomes dependent on the phase stability.[8] The stability factor of a crystal resonator[9] has been defined by the relation $S_f=\omega_0\cdot d\theta/d\omega$, where ω_0 is the resonant frequency and $d\theta/d\omega$ defines the phase slope. For the extremely small angles under consideration in this text, a more convenient expression may be obtained. The phase angle $\theta=\tan^{-1}[-2Q\Delta f/f_0]$, differentiating $d\theta/df\approx-2Q/f_0$ expressed in rad/cps, which is sufficiently accurate when $2Q/f_0 \ll 1$. A relationship is thus established between the Q of the resonator and the crystal phase stability. For the 30-Mc crystal with a loaded Q of 15,000, $d\theta/df=0.001$ rad/cps. Stated otherwise, if the desired stability is 1 cps, the phase stability of the oscillator loop must be maintained within 0.06°. If the same frequency stability of 1 cps is required at UHF, using a ×30 frequency multiplier, then the phase stability must be maintained within 0.002°.

The phase resolution of the crystal is ultimately limited by thermal noise generated by the associated circuitry. If it is assumed that all other sources of oscillator instability are neglected, then the stability of the oscillator will depend on the signal-to-noise ratio established at the amplifier input terminals. This SNR must be related to phase in order to establish a relationship with the phase resolution of the crystal. To accomplish this it is convenient to define levels in terms of phase modulation. This derivation is best illustrated by comparing the crystal-oscillator phase-control system to an ideal phase-control system as shown in Fig. 6. All generators and components in the ideal model are noiseless, and the system is completely insensitive to amplitude changes. The phase detector, or multiplier, provides an error signal that controls the frequency of the local oscillator. With phase coherence established, the input signal $e_1=\cos(\omega_0 t+\theta_1)$, the reference signal $e_2=\sin(\omega_0 t+\theta_2)$, and the output voltage $e_0=k(\theta_1-\theta_2)$. When $\theta_1=\theta_2$, the voltage output $e_0=0$. However, this effectively corresponds to a signal input of $90°\approx 1$ rad rms phase amplitude as indicated by the cosine function of e_1. If the switch S_1 is now closed, and the amplifier has adequate gain, θ_1 will jitter and produce a voltage output $e_0=\pm k\cdot\Delta\theta_1$. The term $\Delta\theta_1$ is the quadrature component or phase jitter of the input signal produced by thermal noise in the resistor and will be directly related to temperature and system bandwidth. An SNR may thus be defined as the ratio of 1 rad rms to the rms phase noise $\Delta\theta_1$, which is exactly analogous to the SNR of signal power to rms noise power in the resistor using Boltzmann's constant. Power levels are thus established for phase modulation with a 0-db reference of 1 rad rms.

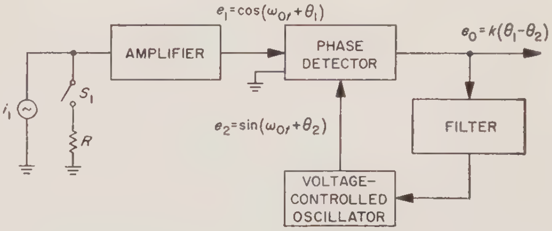
$e_1=\cos(\omega_0 t+\theta_1)$
AMPLIFIER
PHASE DETECTOR
$e_0=k(\theta_1-\theta_2)$
i_1
S_1
R
$e_2=\sin(\omega_0 t+\theta_2)$
FILTER
VOLTAGE-CONTROLLED OSCILLATOR

Fig. 6—Determination of thermal phase-noise with ideal phase-coherent system.

To determine oscillator phase-noise, the phase detector and local oscillator of the ideal receiver are replaced by the crystal resonator where the phase-frequency transfer characteristics of the crystal now maintain coherent oscillations. The SNR for the oscillator is defined in exactly the same manner as for the ideal phase-control system, *i.e.*, by relating the quadrature component of the thermal noise to a 0-db reference level of 1 rad rms.

To obtain the oscillator SNR, the thermal noise at the amplifier input terminals must be determined. The noise contributions of the various components associated with the input circuit of the amplifier must first be summed. The equivalent input circuit to the amplifier may be represented by the circuit shown in Fig. 7, where R_g is the generator resistance, R_θ is the resistance associated with the phase-control circuit, R_s is the series resistance of the crystal, and R_e is the emitter bias resistor. The total noise power will be derived from the sum of the individual noise currents.[7]

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[8] E. P. Felch and J. O. Israel, "A simple circuit for frequency standards employing overtone crystals," Proc. IRE, vol. 43, pp. 596–603; May, 1955.

[9] W. A. Edson, "Vacuum-Tube Oscillators," John Wiley and Sons, Inc., New York, N. Y., ch. 5; 1953.

$$I_T^2 = i_g^2 + i_\theta^2 + i_S^2 + i_e^2$$

where i represents the noise current generated in the equivalent circuit conductance.

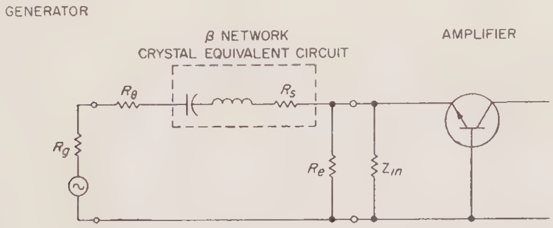


Fig. 7—Equivalent circuit for determination of total thermal-noise power.

The circuit configuration must be recognized, particularly in relation to signal attenuation. Computing the SNR, for example, with the 30-Mc transistorized oscillator, the noise bandwidth as determined by the crystal Q, $B_n = 3000$ cps. Assuming a noise figure for the transistor, $F = 8$ db, and a figure of 10 db for the additional noise represented by the components of I_T, then the total rms noise power $W_n = -121$ dbm. For a signal input of 50 mv and an amplifier input impedance $Z_{\text{in}} = 50$ ohms, the signal input level is -14 dbm, making SNR = 107 db. If we relate the expected phase jitter from the crystal oscillator to 1 rad rms then an SNR of 107 db represents a peak phase jitter of approximately 0.001°. As stated earlier, a stability of 1 cps at 900 Mc was commensurate with an oscillator phase stability of 0.002°. Thus the transistor oscillator in the example should have a stability of the order of $\frac{1}{2}$ cps at 900 Mc. The measured frequency stability of two 960-Mc sources, multiplied from two 30-Mc VHF transistor oscillators has been found to be of the order of 1 cps, as determined by the beat tone. This may be expressed as a stability of $\pm\frac{1}{2}$ cps, which, with the assumptions made, corresponds quite closely to the computed value for 900 Mc. The agreement established indicates that the source of phase noise is thermal noise and that no sizable additional contributions have been made by other oscillator components or the frequency multipliers.

IV. Noise Modulation of an Oscillator

Thermal noise agitation of the oscillator frequency may be considered on a sampling basis as low-level random-impulse modulation where the random frequency shifts are represented as unsymmetrical sidebands of the carrier. However, any one of these single, random-sideband components may be resolved into two pairs of symmetrical and antisymmetrical sidebands representing amplitude and frequency modulation of the carrier, with each pair having half the amplitude of the random component as represented in Fig. 8. This is mathematically demonstrated[10] by taking a random pair of unsymmetrical sidebands

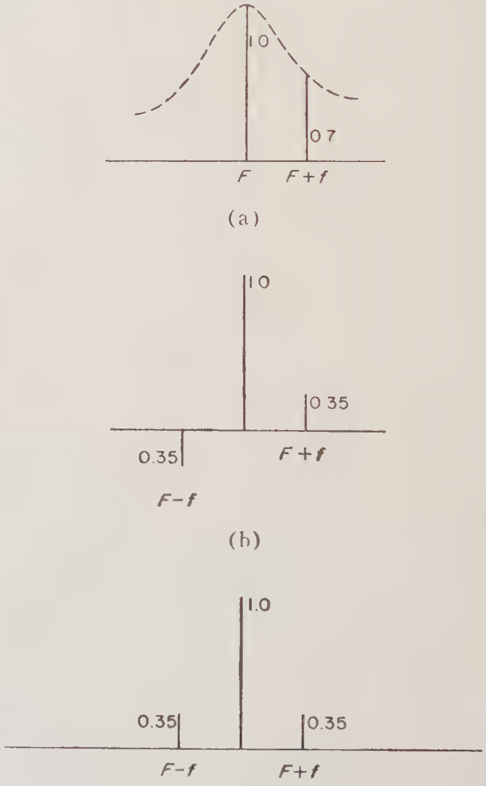
$$B_1 \cos\left[2\pi(F+f)t+\theta_1\right] \quad \text{and} \quad B_2 \cos\left[2\pi(F-f)t-\theta_2\right]$$

separated from the carrier $A \cos 2\pi Ft$ by $\pm f$. No relation is assumed between B_1 and B_2 or between θ_1 and θ_2, and either B_1 or B_2 may be zero. The sum of these two sidebands is

$$\left[B_2 \sin(\omega t+\theta_2) - B_1 \sin(\omega t+\theta_1)\right] \sin \Omega t$$
$$+ \left[B_2 \cos(\omega t+\theta_2) + B_1 \cos(\omega t+\theta_1)\right] \cos \Omega t$$

where $\omega = 2\pi f$ and $\Omega = 2\pi F$.

The quadrature term of interest $\sin \Omega t$ represents the sum of a pair of antisymmetrical sidebands corresponding to frequency modulation. The term in $\cos \Omega t$ repre-



(a)

(b)

(c)

Fig. 8—Impulse-noise modulation of a carrier. (a) Random-noise modulation $= b + c$. (b) Antisymmetrical FM sidebands. (c) Symmetrical AM sidebands.

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[10] S. Goldman, "Frequency Analysis, Modulation and Noise," McGraw-Hill Book Co., Inc., New York, N. Y., ch. 5; 1948.

sents amplitude modulation and for this discussion will be neglected. The instantaneous frequency swing for a large number of random-sideband components will be given by the quadratic sum of these components, including the appropriate phase angles. This frequency modulation aspect of oscillator noise is to be expected from the circuit analysis, where it was shown that noise in the oscillator creates both amplitude and frequency jitter.[2] The noise modulation components will be restricted to those frequencies lying within the band-pass filter characteristics of the crystal resonator.

With the modulation aspect of oscillator noise established, the corresponding phase jitter may be estimated. For any particular random-noise sideband f_m, a modulation index may be defined as the ratio of the frequency deviation produced by the noise and f_m. Thus

$$MI = \frac{\Delta F}{f_m} = \phi$$

where ϕ is now the phase modulation in radians. A particular noise-sideband component is assumed to be offset from a normalized carrier at a frequency corresponding to the half-power point of the frequency spectrum of the oscillator as shown on Fig. 8. From the random-noise-sideband analysis half this amplitude, or 0.35, will represent the amplitude of a hypothetical anti-symmetrical FM sideband. The modulation index that produces sidebands of 0.35 amplitude may be determined from the Bessel functions. A modulation index $\phi = 0.66$ produces spectral amplitudes:

$$J_0(\phi) = 0.894, \qquad J_1(\phi) = 0.312, \qquad J_2(\phi) = 0.05, \text{ etc.}$$

Neglecting terms higher than $J_1(\phi)$, it can be seen that the sidebands are approximately 0.35 of a normalized carrier. The expected phase modulation for a given noise frequency component and a specified frequency stability may thus be determined. As there is an integral relationship between phase and frequency with a $1/s$ function, the phase-noise modulation may be expected to decrease with noise frequency at a rate of 6 db/octave.

V. THE SPECTRUM OF HIGHLY STABLE OSCILLATORS

As stated in Section I, the short-term stability of an oscillator may be defined by the character of the noise spectrum that it produces. The phase-noise spectrum may be measured with a phase-coherent system. The oscillator phase-noise appears as an amplitude-time function at the output of the phase detector.[11] The function must be analyzed as a one-sided spectrum, with the spectral density expressed in rms rad/cps. The power spectrum[12] requires a direct RF spectral measurement which produces a two-sided spectrum relating noise power to frequency. As an alternative, the FM noise-power spectrum may be represented by a statistical distribution of frequencies. The following discussion relates these spectral characteristics to the previous sections and demonstrates measurement techniques.

For oscillators of extremely high spectral purity, especially when located in the UHF region, spectral measurement presents several problems. In a communication system, interest generally is in the combined noise of the transmitter and receiver local oscillators rather than the noise of an isolated oscillator. A noise comparison of two similar oscillators may thus be made to avoid the necessity of having a comparison source of extremely high spectral purity at any specified frequency.

A. Synchronous Systems

Phase noise may be observed by connecting the two oscillators to a phase detector. The output will contain components down to dc and, because of frequency instabilities, a slowly varying beat tone of ±90° amplitude will appear. The sensitivity for small phase perturbations is thus seriously impaired. If phase synchronism is established by making one of the oscillators a VCO and inserting a suitable tracking filter, the LF components may be eliminated from the output of the detector while the sensitivity to random phase jitter is greatly improved. Further improvement in sensitivity may be obtained with frequency multipliers as discussed in Section I.

A block diagram of a phase-coherent system is outlined in Fig. 9. Signals greatly exceeding the amplifier noise levels and AM limiting are assumed. The frequency multipliers are characterized by high-Q tank circuits $Q > 100$, and low multiplication in relation to circuit Q, not > 5. Carefully smoothed power supplies are required to minimize incidental phase modulation. It should be noted that with large multiplication ratios the reference signal B connected directly to the phase detector may now be considered as an ideal sinusoidal source.

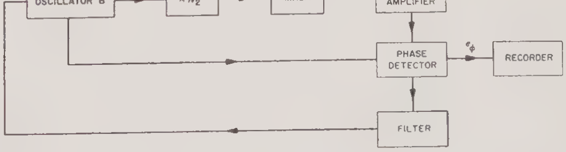

Fig. 9—Measurement of phase noise of two oscillators.

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[11] L. Malling, "The Atomic Clock as a Phase-Stable Oscillator for Deep Space Communication," *Proc. 15th Annual Symposium on Frequency Control*, U. S. Army Sig. Res. and Dev. Lab., Ft. Monmouth, N. J., May, 1961.

[12] That is, the spectrum produced by FM noise components.

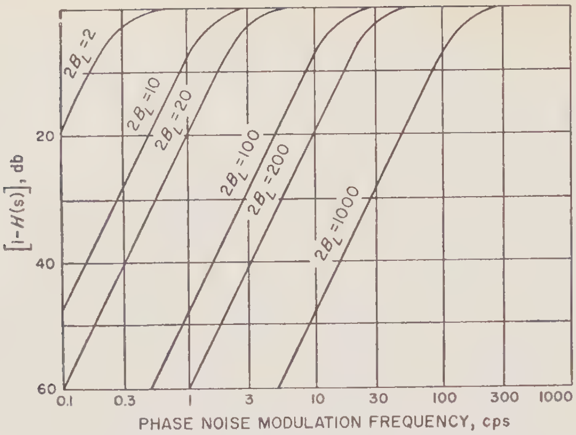

Fig. 10—Characteristics of the loop transfer function.

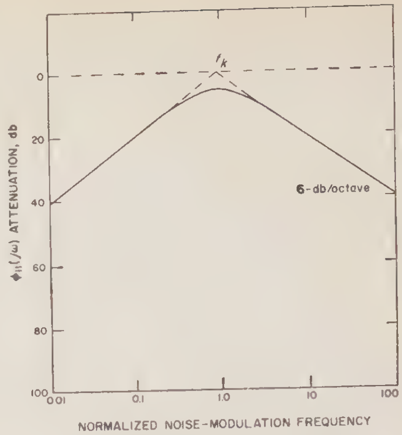

Fig. 11—Spectral characteristics of phase noise with coherent receiver.

The combined oscillator phase-noise is measured as a peak-to-peak signal voltage at the output terminals of the phase detector. The relationship between voltage and phase angle is very nearly linear for excursions less than 0.5 rad. Oscillator B is caused to track variations in oscillator A by virtue of the phase-locked loop. The magnitude e_ϕ of the recorded phase-noise is now dependent on the transfer function $H(s)$ of the RF loop as determined by the filter and other loop constants.[4] This is shown more clearly in Fig. 10, where $|1-H(s)|$ rather than $H(s)$ is plotted as a function of both the phase-noise modulation frequency and loop bandwidth. It will be seen that the loop operates as a high-pass filter so that as bandwidth is decreased, as determined by $H(s)$, there is progressively less attenuation of the lower noise frequency components. For example, at $2B_L=200$ cps, cps, a 3-cps noise component is attenuated 40 db, whereas for $2B_L=20$ cps the attenuation is only 3 db. Thus, the phase noise increases as the receiver bandwidth is decreased. When the spectrum is studied, this will become more apparent.

The relationship between the transfer function $H(s)$ and the loop bandwidth B_L may be calculated using servo-loop analysis. For a damping factor of 0.7, $H(s)$ is given:[4]

$$H(s) = \frac{1 + \left(\frac{3}{4B_L}\right)s}{1 + \left(\frac{3}{4B_L}\right)s + \left(\frac{9}{32B_L^2}\right)s^2}.$$

An instrumentation is thus established which permits inspection of any section of the phase spectrum defined by the servo-loop acting as a high-pass filter.

The phase-noise spectral density of the output signal from the phase detector $\phi_{11}(s) = |1-H(s)|/s$, as determined by the loop transfer function and the $1/s$ phase-frequency function. Hence $\phi_{11}(j\omega)$ will appear as illustrated in Fig. 11, with the power concentrated in a region that is defined by f_k, the corner frequency. If the phase noise is computed for f_c, the 3-db point of the $|1-H(s)|$ characteristic, an approximation may be made to the expected rms phase jitter based on the probability that the maximum noise excursions will be caused by f_k components in the region of f_c. Close agreement is not necessarily expected, since the measured phase noise is to a large degree dependent on the frequency of occurrence of f_k in a random-noise spectrum during the measuring interval.

The determination of rms phase-noise in a coherent system using spectral information is illustrated by taking as an example two 30-Mc transistor oscillators in the phase-coherent system outlined in Fig. 9. For a UHF frequency of 960 Mc multiplied from 30 Mc, the frequency deviation was estimated (in Section II) as $\pm\frac{1}{2}$ cps, so that $\Delta F=0.5$ cps. For a modulation index of $MI=0.66$, the noise modulation component f_m that will produce $\Delta F=0.5$ cps is $f_m=0.75$ cps. Thus the peak phase excursion at 0.75 cps will be 0.66 rad, or 37° peak. If the receiver bandwidth $2B_L=5$ cps, the cutoff frequency f_c, as determined by $|1-H(s)|$, will be 0.80 cps, so that the expected phase excursion at 0.8 cps will be 3.5 db down from the value at 0.75 cps—0.5 db due to the $1/s$ function and 3.0 db due to the $|1-H(s)|$ function, or approximately 8° rms. Measured data for two transistor oscillators for similar system parameters using a phase-coherent loop have indicated an rms phase noise at 960 Mc of the order of 5° rms. The estimated rms noise for the two 30-Mc oscillators without frequency multiplication would be 0.25° rms. Measured data with $2B_L$ adjusted for the same bandwidth have indicated 0.20° rms, which is also somewhat less than the estimated noise. These measurements indicate that any noise contributions from the multipliers are negligible[13] It should be realized, of course, that many prob-

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[13] This may be verified by feeding one of the oscillators into both multipliers and observing the phase noise. The observed noise for this measurement was negligible.

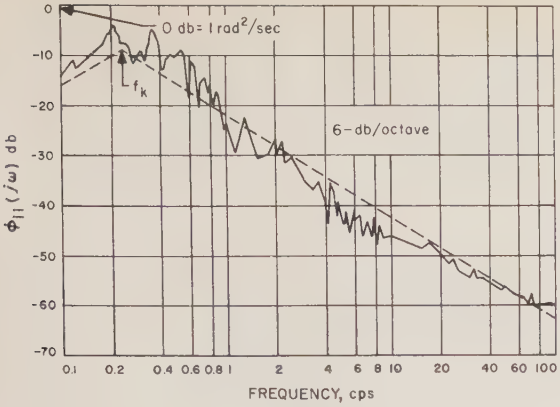

Fig. 12—Phase-noise spectral density for synchronous receiver.

lems arise in the precise measurement of noise. Typically, phase noise is measured as a peak-to-peak deviation with a ratio of 6 to the rms value, as determined by a 3σ probability.

The measured spectral density of the phase noise for a 960-Mc coherent system adjusted for a bandwidth of $2B_L = 2.5$ cps is shown in Fig. 12; it appears quite similar to the estimated characteristics shown in Fig. 11.

B. Nonsynchronous Systems

A direct FM noise-power spectral measurement of the oscillators may be accomplished with a nonsynchronous system by offsetting the transmitter and receiver oscillators to produce a heterodyne tone at the phase detector, now used as a mixer. For extremely narrow-band analysis, mixer distortion terms may be neglected. The spectrum to be investigated is that of an audio tone that will now contain the same noise sidebands as the FM noise sidebands of the two oscillators combined. The beat-tone instrumentation for such a spectral measurement is illustrated in simplified form in Fig. 13 for a 2388-Mc space communication system.

The two oscillators to be investigated are a 31.84-Mc oscillator and a 29.476-Mc VCO multiplied to UHF ×75 and ×80 respectively. The 29.476-Mc VCO is caused to track the Doppler component by the magnitude of the offset frequency f_A. Both oscillators may be phase-locked to sources of higher spectral purity, the Atomichron and a high-Q 5-Mc oscillator, for improved stability.

The power spectral density of the audio tone may be computed as a function of frequency by using the Fourier transform of the autocorrelation function[14] as expressed by

$$\Phi_{11}(s) = \int_{-\infty}^{\infty} \phi_{11}(\tau) e^{-s\tau} d\tau$$

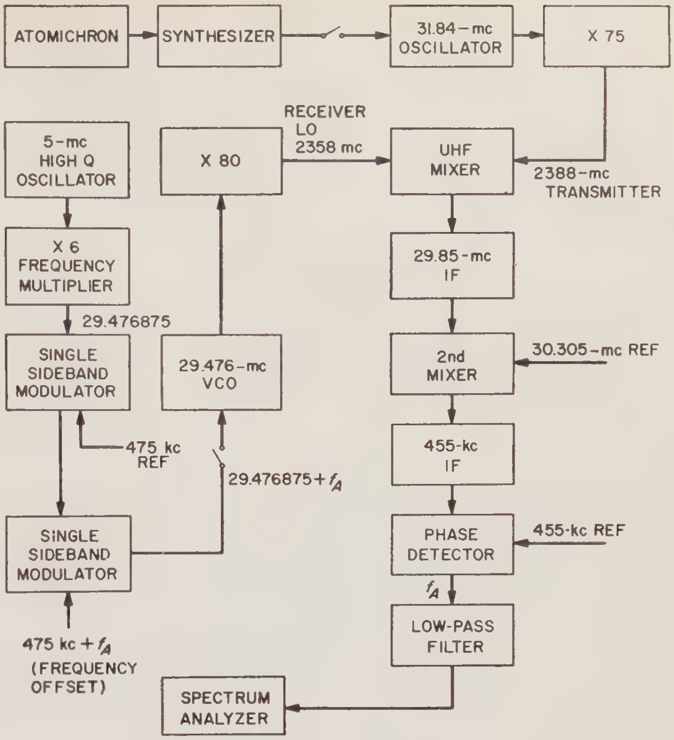
ATOMICHRON
SYNTHESIZER
31.84-mc OSCILLATOR
X 75
RECEIVER LO 2358 mc
5-mc HIGH Q OSCILLATOR
X 80
UHF MIXER
2388-mc TRANSMITTER
X 6 FREQUENCY MULTIPLIER
29.85-mc IF
29.476875
SINGLE SIDEBAND MODULATOR
29.476-mc VCO
2nd MIXER
30.305-mc REF
455-kc IF
475 kc REF
29.476875 + f_A
SINGLE SIDEBAND MODULATOR
PHASE DETECTOR
455-kc REF
f_A
LOW-PASS FILTER
475 kc + f_A (FREQUENCY OFFSET)
SPECTRUM ANALYZER

Fig. 13—Instrumentation for spectrum analysis of nonsynchronous oscillators.

where $\phi_{11}(\tau)$ is the autocorrelation function. The power density spectrum of the signal in terms of its frequency components is then

$$\Phi_{11}(j\omega) = \int_{-\infty}^{\infty} \phi_{11}(\tau) e^{-j\omega t} d\tau,$$

or in the trigonometric form,

$$\Phi_{11}(j\omega) = \int_{-\infty}^{\infty} \phi_{11}(\tau) \cos \omega\tau d\tau.$$

The autocorrelation function is defined by

$$\phi_{11}(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} f_1(t) f_1(t+\tau) dt.$$

The function of the spectrum analyzer is to sample the signal and transform the data into a suitable format for a computer, in this case an IBM 7090. The required computations may then be rapidly performed to determine the power spectral density. The measured power spectrum is shown in Fig. 14 for the two oscillators locked to the phase-stable sources and is seen to be approximately 1 cps wide at the half-power point. The beat frequency in this case was set at 8 cps and the low-pass filter at a cutoff frequency of 50 cps. Data were sampled for $2\frac{1}{2}$ minutes at a rate of 1000/sec. Sufficient computations were made to ensure a resolution of 0.1 cps in the spectrum.[3]

By adopting a different concept, spectrum analysis may be greatly simplified. Thus if the frequency of an

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[14] John G. Truxal, "Automatic Feedback Control System Synthesis," McGraw-Hill Book Co., Inc., New York, N. Y., ch. 7; 1955.

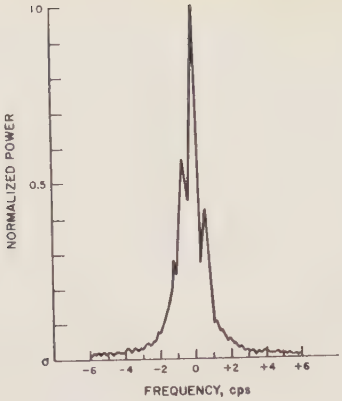

Fig. 14—Combined power spectrum of two 2388–Mc oscillators measured by autocorrelation method.

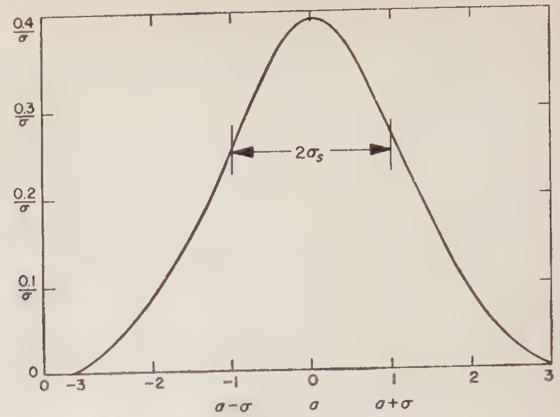

Fig. 15 Gaussian distribution function.

oscillator is considered as the statistical average of a random distribution of frequencies measured in time, the concept of a probability density spectrum may be introduced. If it is further assumed that the frequency jitter is produced by thermal noise, the random phenomenon may be expected to be a Gaussian process.[15] The Gaussian distribution is described by

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-(x-\mu)^2/2\sigma^2\right].$$

A graph of this function for a nonzero expected value is shown in Fig. 15. The spectrum width is now to be defined in terms of the Gaussian probability function. For example, the spectrum width may be defined as $2\sigma_s$, where the region between $a-\sigma$ and $a+\sigma$ is $2\sigma_s$. To record the required data, the spectrum analyzer instrumentation now comprises a frequency or period counter. Frequency is measured at a fixed sampling rate for an extended period. The sampling time must be long enough to ensure an adequate distribution but not so long as to include thermal drifts in the average frequency. Measured frequency is plotted as the abscissa, and the frequency of occurrence, or events, is plotted as the ordinate. Fig. 16 shows a probability spectrum taken for the two oscillators of Fig. 13, first with the stabilization circuitry opened and then with the stabilization switches closed ($2\sigma_s$ equals 12 and 1.5, respectively). The computed probability is shown by the dotted curve. The beat frequency was set to 50 cps, and the sampling rate was once every 2 sec. The probability spectrum of Fig. 16(b) may be compared to the power spectrum of Fig. 14. The spectrums are seen to be quite similar. A period count instead of a frequency count would provide more resolution for an extremely narrow spectrum.

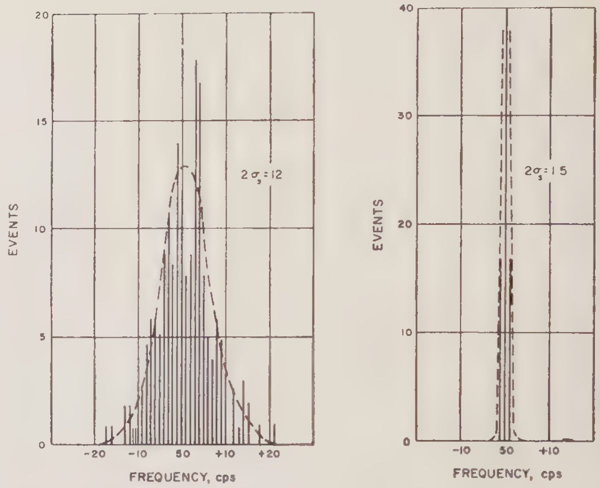

Fig. 16—Combined probability density spectrum for two 2388-Mc oscillators: (a) unlocked, (b) locked to stable source; dashed curve is computed probability.

VI. Recapitulation

A theory has been proposed that explains oscillator phase-noise in terms of well-known laws of thermal agitation. Data have been presented relating power and phase spectrums to oscillator noise. Simplicity of presentation has been given precedence over mathematical rigor. Substantial areas of agreement have, however, been obtained with measured data. The advantage of the Fourier transform plus computer method for determining extremely narrow spectrums has been demonstrated. A simple laboratory technique for spectrum estimation based on frequency probability has been shown to be of value. Oscillator stability has been related to phase-coherent system performance. The value of frequency multipliers in providing improved stability at extremely high frequencies or desirable spectrum-width magnification for observation has been emphasized.

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[15] W. B. Davenport and W. L. Root, "Random Signals and Noise," McGraw-Hill Book Co., Inc., New York, N. Y., ch. 8; 1958.

Harmonic Generation, Rectification, and Lifetime Evaluation with the Step Recovery Diode*

STEWART M. KRAKAUER†, MEMBER, IRE

Summary—This paper deals with a *p-n* junction device which ill be called a "Step Recovery Diode" because its conductivity ariation during reverse recovery approximates a step function. The ansition from reverse storage conduction to cutoff for this diode an occur in about a nanosecond, and it can produce associated iscontinuities up to about an ampere and/or a hundred volts.

This step recovery action can be conveniently used to generate aveforms which are very rich in high-order harmonics in the gigaycle region. In many cases it offers considerable advantage in ciruit simplicity and power-handling capability over alternative diode armonic generators. This paper is concerned with the factors that o into the appropriate mating of this diode with its circuit, and with valuation of the performance that can be achieved.

As a by-product of this analysis, a generalized evaluation of ectification efficiency is obtained which is useful for many convenonal semiconductor diodes in conventional rectifier circuits.

This analysis also leads to a convenient method for evaluating he lifetime of semiconductor diodes, which is particularly useful in he fractional nanosecond range because it separates out capacitive ffects.

INTRODUCTION

SEMICONDUCTOR diodes are widely used as harmonic generating elements because of their nonlinear behavior [1], [2]. Profound generic differnces can exist in the character of this nonlinearity deending upon both the design of the diode and its operting conditions. These differences in nonlinear behavior ead to fundamental differences in harmonic generating apability.

The harmonic generating diode is conventionally perated within its reverse saturation region so as to void both forward conduction and avalanche breakown [3]–[8], [16]. Under these conditions, the diode vill act as a voltage variable capacitor having some disipation. Conversion efficiency has been found to drop ff very rapidly with increasing harmonic order because he available harmonic power output drops off so apidly. For this reason, efficient harmonic generation in his mode usually requires a cascade of doublers and riplers. Several of the above workers have reported ome improvement in performance when intermittent orward conduction was permitted—though their analses were limited to reverse conduction only.

If the harmonic generating diode is operated with ntermittent forward conduction, then its dynamic perormance will depend very strongly upon minority carier lifetime and junction retarding field [9]. Minority arrier lifetime determines both the amount of stored harge that remains in the junction at the onset of reverse recovery and the rate of carrier recombination during recovery. The junction field determines the availability of stored charge for removal from the junction by storage conduction, and hence the speed of transition from storage conduction to cutoff.

If the minority carrier lifetime is assumed to approach zero, then the diode response will approach that of a voltage-dependent resistance since no storage is then involved. Page [10] has shown that the maximum conversion efficiency that can be achieved with the zero lifetime diode is $1/n^2$ where n is the harmonic number.

If, on the other hand, the minority carrier lifetime is assumed to approach infinite value, then the diode response will approach that of a voltage-dependent capacitor. Hysteresis will be associated with the cyclic excitation of this diode because of stored charge dispersion and this will contribute to diode dissipation. This hysteresis will diminish with increasing retarding field gradient. Discussion of the application of this device to harmonic generation has appeared in the literature [11], [12], [15].

This paper deals specifically with the circuit properties of those diodes having high junction retarding fields and finite lifetime. Operationally, these diodes switch very abruptly from reverse storage conduction to cutoff. The value of this device for harmonic generation depends very much upon the speed of this transition and upon the existence of an appropriate reverse storage conduction phase preceding this transition.

Some difficulty has arisen in finding an appropriate name for this diode. Leenov and Uhlir's [11] "Nonlinear Capacitor" is somewhat too restrictive since it implies infinite lifetime, and it does not account for charge dispersion. "Charge Storage Diode" [9] implies a broader class of diodes than are considered here. In this laboratory, we have grown accustomed to calling this device a "Boff Diode." There is much historical [12] and onomatopoeic justification for this term, but convention requires that electronic devices be named for performance characteristic, structure, or underlying mechanism. In this paper, the term "Step Recovery Diode" has been chosen as descriptive of that property of the diode which makes it useful. During the initial phase of reverse recovery, the conductivity of this diode will remain essentially at its forward conduction value due to the conductivity modulation associated with minority carrier storage. This storage conduction phase will last until the stored minority carriers resulting from forward conduction have been depleted by the flow of reverse current and by minority carrier recombination.

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* Received September 25, 1961; revised manuscript received, Iarch, 1962.

† hp associates, Palo Alto, Calif.

Reverse storage conduction then terminates very abruptly and the diode conductivity drops very suddenly to the low value usually associated with reverse saturation. Thus the diode conductivity variation during reverse recovery approximates a step function.

The dynamic behavior of the step recovery diode depends very strongly on the current, voltage, and impedance levels of its associated circuit. This paper is concerned with the factors that go into the appropriate mating of the step recovery diode with its circuit for harmonic generation and with evaluation of the performance that can be achieved.

As a by-product of this analysis, a generalized evaluation of rectification efficiency is obtained which is generally useful for many conventional semiconductor diodes in conventional rectifier circuits. Also, a method is derived which permits convenient evaluation of diode lifetime in the fractional nanosecond range.

THE STEP RECOVERY DIODE

The underlying physical mechanisms and behavior of step recovery diode are treated extensively by Moll, *et al.* [9]. It is seen in that paper that the diode should have the highest possible junction gradient consistent with lifetime and avalanche breakdown considerations, and that an optimum junction area exists which best compromises the degradations in transition due to capacitive loading and charge storage dispersion.

A minimum diode voltage transition time $T_{t\,\min}$ was derived by Moll, *et al.*, in their eq. (42) [9] assuming a resistive source impedance:

$$T_{t_{\min}} \approx 1.26\left[\left(\frac{\epsilon}{V}\right)\left(\frac{1}{N_0 b}\right)^2\left(\frac{Q_0 R}{qb}\right)^3\right]^{2/15}\left[\frac{1}{D}\right]^{3/5} \qquad (1)$$

under condition that diode lead inductance L and junction area A were the following optimum values:

$$L = \frac{R^2 C_v}{4} \qquad (2)$$

$$A = .7\left[\frac{Q_0{}^2 V}{(q\epsilon b)^2 (N_0 b R)^3}\right]^{1/5} \qquad (3)$$

where

$N_0 = N_s \operatorname{erfc}(W/4\sqrt{Dt})$
$b = W/4Dt$
ϵ = permittivity
V = maximum reverse voltage across diode
N_s = surface concentration
W = wafer thickness
D = diffusion constant
t = diffusion time
Q_0 = stored charge
R = Thévenin generator resistance
q = electron charge
C_v = diode incremental capacitance at the end of transition
$N_0 b$ = gradient of impurities at the junction.

In practice, currents in the order of an ampere and voltages in the tens of volts can be switched in less than a nanosecond.

DYNAMIC EQUILIBRIUM

The conventional half-wave rectifier circuit shown in Fig. 1(a) is assumed as a convenient prototype. It will be seen that this circuit is quite general. In order to evaluate its harmonic generating capabilities, it will first be necessary to evaluate the dynamic equilibrium conditions that result when sinusoidal excitation is applied.

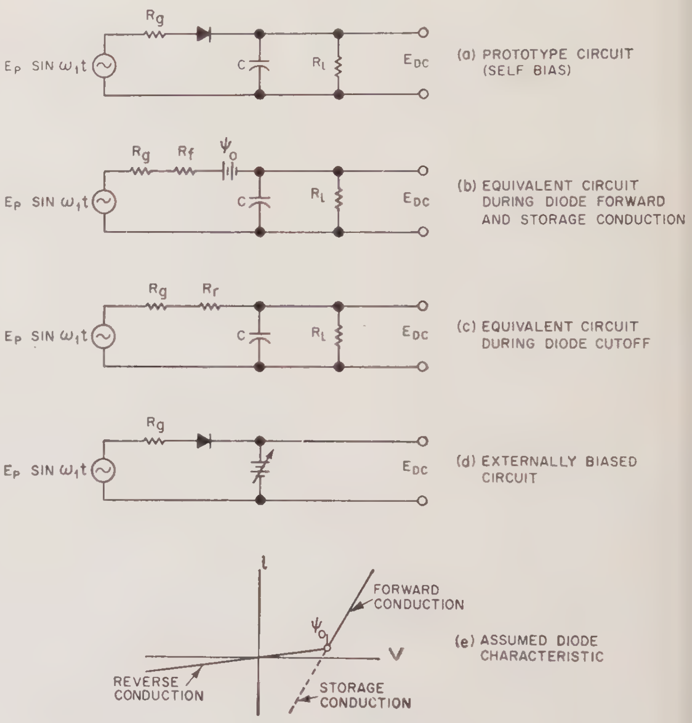
Rg
Ep SIN ω1t
C
RL
EDC
(a) PROTOTYPE CIRCUIT (SELF BIAS)
Rg Rf ψ0
Ep SIN ω1t
C
RL
EDC
(b) EQUIVALENT CIRCUIT DURING DIODE FORWARD AND STORAGE CONDUCTION
Rg Rr
Ep SIN ω1t
C
RL
EDC
(c) EQUIVALENT CIRCUIT DURING DIODE CUTOFF
Rg
Ep SIN ω1t
EDC
(d) EXTERNALLY BIASED CIRCUIT
i
FORWARD CONDUCTION
ψ0
V
REVERSE CONDUCTION
STORAGE CONDUCTION
(e) ASSUMED DIODE CHARACTERISTIC

Fig. 1—Prototype half-wave rectifier circuit.

The step recovery diode is assumed, for this calculation, to have an instantaneous transition from reverse storage conduction to cutoff. It is further characterized by the following parameters:

τ = minority carrier lifetime
ψ_0 = nominally the electrostatic junction potential, but this parameter may be chosen as some other value which will give the best fit in conjunction with R_f and R_r to the diode characteristic for the signal level applied
R_f = forward resistance (a linear approximation to the forward conduction characteristic)
R_r = reverse resistance (this includes saturation conduction).

The assumed form for these diode characteristics is shown in Fig. 1(e). All of these parameters are somewhat temperature dependent and the choice of appropriate parameter values for a given diode will depend somewhat upon its dynamic operating range.

Parameter values for the associated circuit are taken s follows:

1) Source impedance is assumed to be purely resistive and is represented as R_g. R_g is added to R_f to give R_c, the effective series charging resistance for C. This is shown in Fig. 1(b).
2) R_d is the effective resistance discharging C. During the entire cycle, leakage current flows through R_l and during the period of diode reverse bias there is an additional leakage component through the diode. Total effective leakage may be calculated as follows:

$$i_d = \frac{E_{DC}}{R_l} + \frac{1}{2\pi}\int_{\theta+\phi}^{2\pi+\theta}\left(\frac{E_{DC} - E_p \sin \omega_1 t}{R_g + R_r}\right) d\omega_1 t \qquad (4)$$

where θ is the angle of diode current initiation, and ϕ is the diode conduction angle as shown in Fig. 2.

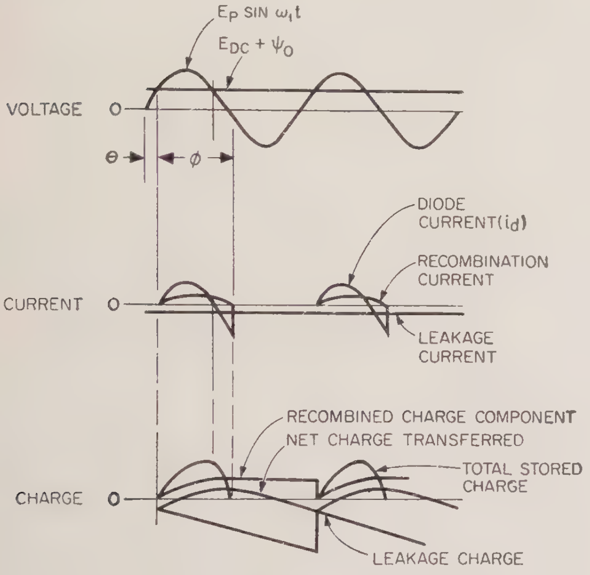
E_P SIN $\omega_1 t$
$E_{DC} + \psi_0$
VOLTAGE
0
θ
ϕ
DIODE CURRENT(i_d)
RECOMBINATION CURRENT
CURRENT
0
LEAKAGE CURRENT
RECOMBINED CHARGE COMPONENT
NET CHARGE TRANSFERRED
TOTAL STORED CHARGE
CHARGE
0
LEAKAGE CHARGE

Fig. 2—Equilibrium waveforms associated with the half-wave rectifier circuit.

Substituting:

$$E_p = \frac{E_{DC} + \psi_0}{\sin\theta} \approx \frac{E_{DC}}{\sin\theta} \qquad (5)$$

and solving:

$$i_d = E_{DC}\left[\frac{1}{R_l} + \frac{1 - \dfrac{\phi}{2\pi} + \dfrac{\cos\theta - \cos(\theta+\phi)}{2\pi\sin\theta}}{R_g + R_r}\right] \qquad (6)$$

and so an effective leakage resistance R_d may be defined

$$\frac{1}{R_d} = \frac{1}{R_l} + \frac{1 - \dfrac{\phi}{2\pi} + \dfrac{\cos\theta - \cos(\theta+\phi)}{2\pi\sin\theta}}{R_g + R_r} \qquad (7)$$

and

$$\frac{R_c}{R_d} = \frac{R_g + R_f}{R_l} + \frac{R_g + R_f}{R_g + R_r} \cdot \left(1 - \frac{\phi}{2\pi} + \frac{\cos\theta - \cos(\theta+\phi)}{2\pi\sin\theta}\right). \qquad (8)$$

Since R_c/R_d must be known in order to solve for θ and ϕ, an approximate value for R_c/R_d may first be evaluated assuming $\phi = 0$.

$$\frac{R_c}{R_d} \approx \frac{R_g + R_f}{R_l} + \frac{R_g + R_f}{R_g + R_r}. \qquad (9)$$

Given $\omega_1\tau$, θ and ϕ may be reevaluated from the intersection of R_c/R_d and $\omega_1\tau$ in Fig. 3. Referring back to (8), R_c/R_d may be reevaluated and substituted back into Fig. 3 to find a more precise value for θ and ϕ.

3) C is assumed sufficiently large so that $R_d\omega_1 C \gg 1$. The voltage across C can therefore be assumed to have no appreciable ac component.

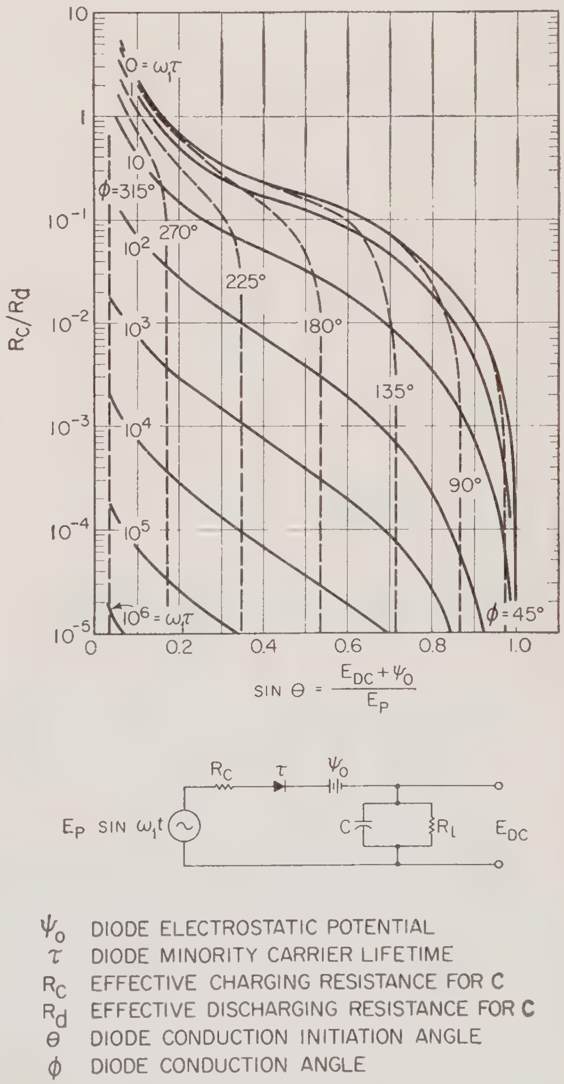

Fig. 3—Equilibrium values for the half-wave rectifier circuit.

If this circuit is to be used as a detector, then attention will center upon the dc voltage which becomes established across C. For harmonic generation, the diode voltage or current waveforms assume major importance. The steady-state waveforms which are associated with the response of this circuit are shown in Fig. 2. Diode forward conduction starts (current initiation angle θ) essentially when the supply voltage exceeds the dc level across C plus the barrier (or offset) potential of the diode (ψ_0). Diode current will continue to flow (conduction angle ϕ) for a time after the supply voltage has dropped below that level at which current had been initiated. When the stored charge has again dropped to zero, the diode current ceases.

In order to solve for the steady-state equilibrium conditions that exist in the diode, the continuity of stored charge (Q) is considered (see [9], eq. (22))

$$\frac{dQ}{dt} + \frac{Q}{\tau} = i_d \tag{10}$$

where

$$i_d = \frac{E_p}{R_c}\left[\sin\left(\omega_1 t + \theta\right) - \sin\theta\right], \tag{11}$$

the diode current pictured in Fig. 2, and

$$\theta = \sin^{-1}\left[\frac{E_{DC} + \psi_0}{E_p}\right]. \tag{12}$$

This equation is solved for Q

$$Q = \left(\frac{E_p \sin\theta}{R_c}\right)\left(\frac{\omega_1}{\omega_1^2 + \tau^{-2}}\right) \cdot \left[\left(\frac{\cot\theta}{\omega_1\tau} + 1\right)\sin\omega_1 t + \left(\frac{1}{\omega_1\tau} - \cot\theta\right)\cos\omega_1 t + \left(\cot\theta + \omega_1\tau\right)\epsilon^{-\omega_1 t/\omega_1\tau} - \left(\frac{1}{\omega_1\tau} + \omega_1\tau\right)\right]. \tag{13}$$

At equilibrium, the following two conditions must be satisfied:

1) Diode conduction ceases when its stored charge drops to zero, so when $Q=0$, $\omega_1 t=0$, ϕ.
2) Total charge added to the capacitor per cycle is equal to the diode recombined charge, and is equal also to charge lost by leakage through R_d.

These conditions relate the four system parameters $\omega_1\tau$, ϕ, θ, and R_c/R_d as follows:

$$\cot\theta = \frac{-\omega_1\tau\sin\phi - \cos\phi + \omega_1^2\tau^2\left(1 - \epsilon^{-\phi/\omega_1\tau}\right) + 1}{\sin\phi - \omega_1\tau\cos\phi + \omega_1\tau\epsilon^{-\phi/\omega_1\tau}} \tag{14}$$

$$\frac{R_c}{R_d} = \frac{1}{2\pi}\left(\frac{\omega_1\tau}{\omega_1^2\tau^2 + 1}\right) \cdot \left[\left(\frac{\cot\theta}{\omega_1\tau} + 1\right)(1 - \cos\theta) + \left(\frac{1}{\omega_1\tau} - \cot\theta\right)\sin\phi + \omega_1\tau\left(\cot\theta + \omega_1\tau\right)\left(1 - \epsilon^{-\phi/\omega_1\tau}\right) - \phi\left(\frac{1}{\omega_1\tau} + \omega_1\tau\right)\right]. \tag{15}$$

The relationships defined by (14) and (15) are plotted in Fig. 3 by assuming values for ϕ and $\omega_1\tau$ and solving successively for $\cot\theta$ and R_c/R_d.

RECTIFICATION EFFICIENCY

Rectification efficiency can be inferred from Fig. 3 since:

$$\text{rectification efficiency} = \frac{E_{DC}}{E_p} = \sin\theta - \frac{\psi_0}{E_p}. \tag{16}$$

This evaluation will give a good approximation even when the recovery characteristic for a given diode departs considerably from the assumed step behavior, so long as an appropriate value is chosen for equivalent lifetime. It is seen from this plot that the forward to backward resistance of a given diode may constitute as severe an ultimate limitation on rectification efficiency as lifetime. This consideration will become increasingly important for low signal level operation of a given diode since forward and back resistance then approach each other. At very high frequencies, diode inductance and capacitance play increasingly important roles and so departure from the performance predicted from Fig. 3 would be anticipated since these parameters are not taken into account. Generally, low reverse voltage diffused diodes are more apt to approach step recovery behavior than are alloy diodes. Higher voltage diodes and PIN types will depart farthest, not only because their retarding fields are low, but also because transit time may become appreciable.

As an example of a typical use of Fig. 3 for rectification efficiency evaluation, let us assume a 500 Mc, 50 ohm, 5 v (rms) source driving a diode with lifetime of 10 nsec, R_f of 10 ohms and R_r of 1 megohm. R_l is assumed to be 100 K ohms and $C=0.0001$ μf.

1) $\omega_1\tau = (6.28 \times 5 \times 10^8)(10^{-8}) = 31.4$
2) $R_c = R_g + R_f = 60$ ohms
3) $R_d \approx 100$ K ohms (from (7))
4) $R_d\omega_1 C = (10^5)(3.14 \times 10^9)(10^{-10}) = 3.14 \times 10^4 \gg 1$ so C is large enough to keep ripple low
5) $R_c/R_d \approx (60/100) \times 10^{-3} = 6 \times 10^{-4}$
6) $\sin\theta = 0.83$ (from Fig. 3)
7) $RE = 0.73$ (from (16)).

If, for instance, R_l in the above example is reduced to 10 K it becomes readily apparent from Fig. 3 that $\sin\theta$ will drop to about 0.64 and RE to about 0.54. On the other hand, if ω_1 is dropped to 50 Mc, then $\omega_1\tau$ would be 3.14, $\sin\theta$ would be about 0.94 and RE would rise to 0.84.

STEP RECOVERY DIODE HARMONIC GENERATION

The customary requirements for any harmonic generator can be expressed in the following terms:

1) Power output capability
2) Conversion efficiency
3) Output spectral purity
4) Stability and reliability
5) Simplicity and flexibility
6) Cost.

We will attempt here to evaluate the performance of step recovery diode harmonic generators with sufficient accuracy to establish ultimate capabilities, permit evaluation against the above listed requirements, and provide a circuit design philosophy.

1) Power Output Capability

The assumed prototype circuit for harmonic generation is shown in Fig. 4. It is similar to that of Fig. 1(a) except that the generator impedance has been generalized and a resonant cavity filter and load have been added. Magnetic-field excitation of the cavity has been assumed for impedance matching considerations that will be discussed later. The behavior of this circuit will be analyzed by solving for the equivalent Thévenin current generator as seen looking back from the filter input. The particular harmonic component of interest will then be substituted for the actual current source. Looking the other way, the filter and its load will be characterized in terms of the input impedance to the filter with the load connected.

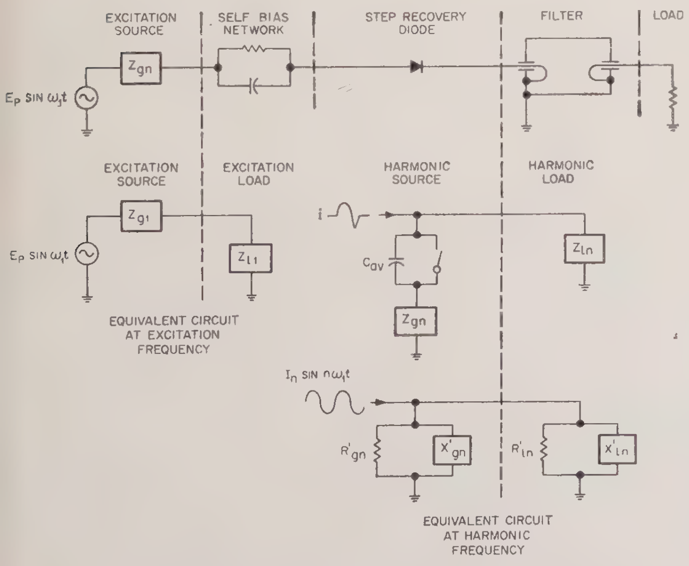

Fig. 4—Single-stage step recovery diode harmonic generator.

The harmonic source current is taken as the diode current defined in Figs. 2 and 3. This initial formulation assumes that Z_g is resistive, that introduction of the filter and the load do not appreciably influence the step recovery diode action, and that the current interruption is instantaneous. Relaxation of these assumptions will be considered as perturbations. Actually, both the conduction interval and the cutoff characteristic of the diode will be influenced by the introduction of the filter and load, because the reflected signal will modify initiation and termination of conduction. The extent of this interaction and hence the validity of the foregoing assumptions will depend upon the tightness of coupling of the drive circuit to the cavity, and hence upon the output power.

Considering the harmonic source current, it is defined in terms of two regions:

$$\begin{cases} i_d = 0 & (\theta+\phi) \leq \omega_1 t \leq (2\pi+\theta) \\ i_d = \dfrac{E_p}{R_c}(\sin\omega_1 t - \sin\theta) & \theta \leq \omega_1 t \leq (\theta+\phi) \end{cases} \cdot \quad (17)$$

The harmonic spectrum that is associated with this waveform can be evaluated by conventional Fourier analysis.

$$i_d = \frac{E_p}{R_c}\left[\int\frac{A_0}{2} + \sum_{n=1}^{\infty}(A_n\cos n\omega_1 t + B_n\sin n\omega_1 t)\right] \quad (18)$$

where

$$A_0 = \frac{1}{\pi}\int_{\theta}^{\theta+\phi}(\sin\omega_1 t - \sin\theta)d\omega_1 t \quad (19)$$

$$A_n = \frac{1}{\pi}\int_{\theta}^{\theta+\phi}(\sin\omega_1 t - \sin\theta)(\cos n\omega_1 t)d\omega_1 t \quad (20)$$

$$B_n = \frac{1}{\pi}\int_{\theta}^{\theta+\phi}(\sin\omega_1 t - \sin\theta)(\sin n\omega_1 t)d\omega_1 t \quad (21)$$

$$C_n = \sqrt{A_n^2 + B_n^2} \quad (22)$$

and ω_1 is the excitation radian frequency.

The A_0 term establishes the capacitor charging current and has already been accounted for in the equilibrium condition evaluation leading up to Fig. 3. The A_1 and B_1 terms ($n=1$) will be of special interest for impedance considerations relating to the fundamental excitation frequency. A_n and B_n combine to give C_n, the peak amplitude of the nth harmonic term.

Substituting and solving:

$$A_1 = \frac{1}{2\pi}\left[\sin(\phi+\theta) - \sin\theta\right]^2 \tag{23}$$

$$B_1 = \frac{1}{2\pi}\left\{\phi - \cos(\phi+\theta)\left[\sin(\phi+\theta) - \sin\theta\right] + \sin\theta\left[\cos(\phi+\theta) - \cos\theta\right]\right\} \tag{24}$$

$$C_n = \frac{1}{\pi(n^2-1)^{1/2}}\left\{\begin{array}{l}\left[\sin(\phi+\theta) - \sin\theta\right]^2 + \dfrac{2}{n}\sin n\phi\cos\theta\left[\sin\theta - \dfrac{n^2}{n^2-1}\sin(\phi+\theta)\right] \\ \quad + \dfrac{2}{n^2-1}(1-\cos n\phi\cos\phi) - \dfrac{2\sin^2\theta}{n^2}(1-\cos n\phi) \\ \quad + \dfrac{2\sin n\phi\sin\theta\cos(\phi+\theta)}{n(n^2-1)}\end{array}\right\}^{1/2}. \tag{25}$$

In (25) the expression $[\sin(\phi+\theta)-\sin\theta]$ is equivalent to the amplitude of the step transition. For high step amplitude and high harmonic number,

$$C_n \approx \frac{\sin(\phi+\theta) - \sin\theta}{\pi n}, \tag{26}$$

and harmonic content becomes proportional to the step amplitude and inversely proportional to the harmonic number as might have been anticipated. In contrast, the half-wave rectifier waveform produces harmonics which are proportional to n^{-2} and so drop off very much more rapidly with harmonic number. Calculated harmonic spectra for two typical current waveforms are shown in Fig. 5. Step amplitude as a function of $\omega_1\tau$ and θ is shown in Fig. 6.

The advantage of bias is seen in Fig. 6 as leading to the possibility of achieving normalized step amplitudes greater than unity (which is the maximum without bias), and also compensating for variation in diode lifetime. Equivalent transition amplitudes can also be achieved with less required diode storage and conduction angle. This helps to improve transition speed, and reduces loading of the cavity by the driving circuit; hence output may be increased.

It may be desirable, in some cases, to dispense with the self-bias produced by the R_dC network and introduce instead an arbitrary external bias, E_{DC} as shown in Fig. 1(e). Sin θ can then be calculated directly.

$$\sin\theta = \frac{E_{DC} + \psi_0}{E_p} \tag{27}$$

and ϕ can be determined from the intersection of sin θ with $\omega_1\tau$ in Fig. 3, or from (14). Self-bias is usually simpler to use and in addition it may tend to produce a more stable output.

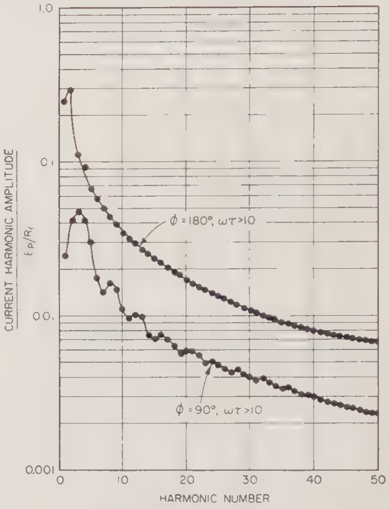

Fig. 5—Harmonic spectrum for assumed circuit values.

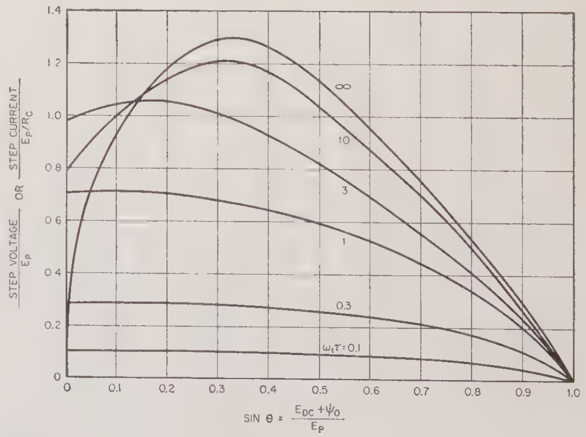

Fig. 6—Step amplitude as a function of circuit values.

In the foregoing analysis, the diode discontinuity was assumed to be instantaneous. Finite transition times result in attenuation of the upper-order harmonics. Adopting a single pole approximation for diode cutoff; with a 10 to 90 per cent transition time of T, the harmonic at frequency $f=0.35/T$ will be down approximately 6 db and will degrade approximately an additional 6 db each octave.

The equivalent harmonic source current including the transition speed degradation will then be

$$i_n = \frac{1}{[1 + 0.2(n\omega_1 T)^2]^{1/2}}\left(\frac{E_p C_n}{R_c}\right)\sin n\omega_1 t \tag{28}$$

where C_n is given in (25) or (26). The rms value of this current is simply

$$I_n = \frac{0.707}{[1 + 0.2(n\omega_1 T)^2]^{1/2}}\left(\frac{E_p C_n}{R_c}\right), \tag{29}$$

or if (26) applies (high n)

$$I_n = \left(\frac{0.707}{[1+0.2(n\omega_1 T)^2]^{1/2}}\right)\left(\frac{E_p}{R_c}\right)\left(\frac{\sin(\phi+\theta)-\sin\theta}{\pi n}\right)\cdot \tag{30}$$

An average capacitance value (C_{av}) is taken as that capacitance value which is associated with the average value of reverse bias voltage V_{av}.

$$V_{\text{av}} = -\frac{1}{2\pi - \phi}\int_{\phi+\theta}^{2\pi+\theta}(E_p \sin\omega_1 t - E_p \sin\theta + \psi_0)\,d\omega_1 t \tag{32}$$

$$V_{\text{av}} = -E_p\left[\frac{\cos(\phi+\theta) - \cos\theta}{2\pi - \phi} - \sin\theta\right] + \psi_0 \tag{33}$$

and

$$C_{\text{av}} \approx \frac{C_0}{\left(1 + \frac{V_{\text{av}}}{\psi_0}\right)^{1/n}}\cdot \tag{34}$$

The diode is accordingly assumed to be represented either as a short circuit during conduction or as a capacitance C_{av} during cutoff.

Power transfer may now be evaluated; considering $Z_{gn} = R_{gn} + jX_{gn}$ and $Z_{Ln} = R_{ln} + jX_{ln}$, then power input to the cavity is

$$P_{in} = \frac{I_n^2 R_{ln}(R_{gn}^2 + X_{gn}^2)}{2\pi}\left[\frac{\phi}{(R_{gn} + R_{ln})^2 + (X_{gn} + X_{ln})^2} + \frac{2\pi - \phi}{(R_{gn} + R_{ln})^2 + (X_{gn} + X_{ln} + X_{c_{\text{av}}})}\right]\cdot \tag{35}$$

Considering now the harmonic source shunt impedance, it consists of the diode (alternately conducting and cut off) in series with the impedance at the harmonic frequency of Z_{gn}. The bias network and other stray impedances are assumed to be lumped with Z_{gn}. It is now desired to calculate the optimum filter input impedance for maximum power transfer. This problem is complicated by the cyclic source impedance variation that is associated with conduction and cutoff of the step recovery diode.

During diode conduction ϕ the source shunt impedance is essentially Z_{gn}. This condition is shown in Fig. 4 by switch closure across the equivalent diode capacitance. When the diode is cut off, its incremental capacitance varies as a function of the instantaneous voltage:

$$C \approx \frac{C_0}{\left(1 + \frac{V}{\psi_0}\right)^{1/n}} \tag{31}$$

where

C_0 is the zero bias capacitance
V is the maximum reverse voltage
ψ_0 is the diode electrostatic potential
n will usually lie between 3 and 6.

This expression is difficult to evaluate for maximum P_{in} and so for simplicity, an equivalent source impedance is taken as the weighted average of the impedance values that exist during each phase of diode conduction.

$$Z_{gn}' = R_{gn} + j[X_{gn} + X_{c_{\text{av}}}(1 - \phi/2\pi)]. \tag{36}$$

It will be easier to work with this impedance in its parallel element form:

$$R_{gn}' = \frac{R_{gn}^2 + [X_{gn} - X_{c_{\text{av}}}(1 - \phi/2\pi)]^2}{R_{gn}} \tag{37}$$

$$X_{gn}' = \frac{R_{gn}^2 + [X_{gn} - X_{c_{\text{av}}}(1 - \phi/2\pi)]^2}{X_{gn} - X_{c_{\text{av}}}(1 - \phi/2\pi)}\cdot \tag{38}$$

Cavity input impedance for optimum power transfer may now be determined. The shunt resistance looking into the cavity should be equal to R_{gn}' and the reactance should be equal in magnitude and opposite in sign to X_{gn}'. It may be desirable to add an appropriate reactive element across the cavity input or detune it slightly to optimize match conditions.

Assuming optimum match conditions, the harmonic power into the cavity will be

$$P_{in} = \frac{I_n^2 R_{gn}'}{4}, \tag{39}$$

and for maximum step amplitude and instantaneous component of cutoff due to junction charge dispersion

$$P_{in} = 0.021\left(\frac{E_p}{nR_c}\right)^2 R_{gn}', \tag{40}$$

so that R_{gn}' should be made high. From (37), this means that R_{gn} and ϕ should be as small as possible, and $X_{c_{\mathrm{av}}}$ as large as possible. $X_{c_{\mathrm{av}}}$ cannot be increased indefinitely because a reduction in diode capacitance will be accompanied by an increase in the component of cutoff time associated with stored charge dispersion (see [9], eq. (35)).

2) Conversion Efficiency

Conversion efficiency is the ratio of harmonic power dissipated in a load to the power which would have been dissipated at the excitation frequency into a matched load connected to the source.

The excitation frequency current produced by the excitation voltage source is given by substituting (23) and (24) into (18)

$$i_1 = \frac{E_p}{2\pi R_c}\left\{[\phi - \cos(\phi+\theta)(\sin(\phi+\theta) - \sin\theta) + \sin\theta(\cos(\phi+\theta) - \cos\theta)]\sin\omega_1 t + [\sin(\phi+\theta) - \sin\theta]^2\cos\omega_1 t\right\}. \tag{41}$$

Since the sinusoidal component of current at fundamental frequency is in phase with the excitation voltage, it determines the total power input to the system, including generator losses. If the power loss in R_{g1} is subtracted out, the power into the harmonic generating network alone may be evaluated:

$$P_1 = \left(\frac{E_p}{R_c}\right)^2\left(\frac{R_cB_1 - R_{g1}(A_1^2 + B_1^2)}{2}\right) \tag{42}$$

where A_1 and B_1 are given respectively in (23) and (24).

P_1 is the power dissipated by the bias resistor and the diode during forward and reverse conduction with the filter input shunted. For low $\omega_1\tau$ the bias dissipation may well be dominant while with very high $\omega_1\tau$ this resistance value tends to increase and so its loss contribution will drop.

The excitation frequency impedance seen by the generator can be computed from (41)

$$Z_1 = \frac{R_cB_1}{A_1^2 + B_1^2} - R_{g1} - j\,\frac{R_cA_1}{A_1^2 + B_1^2}\,. \tag{43}$$

This impedance will have a reactance component (which can be tuned out) and a resistance. A transformer or tuned circuit used for impedance transformation may be desired to optimize coupling between the generator and its driven circuit.

Assuming optimum excitation frequency match, conversion η will be the harmonic frequency power output divided by the excitation power input.

$$\eta = \frac{P_{in} - P_f}{P_1 + P_{in}} \tag{44}$$

where

P_{in} is harmonic power into the filter
P_f is harmonic power loss in the filter
P_1 is excitation power input to the harmonic generator when the filter input is shorted.

The detailed shift in equilibrium conditions of the step recovery diode that would be involved in generating useful output power have been bypassed here, and power conservation alone was considered. This assumption becomes increasingly valid with low-efficiency operation but may introduce substantial error when P_{in} exceeds 10 per cent of P_1.

3) Output Spectral Purity

Generally, as the resonant cavity coupling to the load and especially to the excitation source becomes increasingly tight, the output spectral purity will diminish. Effective Q of the filter decreases with loading and thereby produces amplitude modulation with resulting sidebands. The varying load at the input port produces frequency modulation of the resonant cavity and hence sidebands. It must also be remembered that the cavity will tend to respond to multiples of its fundamental frequency. If the cavity is operated near cutoff, its harmonic frequencies will not be integrally related to its fundamental frequencies because of differing propagation velocities, and so multiple resonant responses may be diminished. Multiple resonant responses may also be diminished through proper location of the excitation and output probes. A high cavity Q is desirable for low amplitude modulation, though the increased size associated with high Q will tend to increase multiple responses. The frequency-modulation-induced sidebands cannot be effectively controlled by cavity Q, but only by minimizing the cyclic change in impedance looking out from the input port. This problem can be handled through appropriate circuitry, as will be discussed later. Extraneous responses can also be minimized by additional filtering [13].

Assuming an average loaded Q_n for the resonant cavity, then the carrier and its sidebands will be related as follows:

$$S_n \approx \frac{1 - \epsilon^{-\pi n/Q_n}}{2\pi[(n/2Q_n)^2 + N^2]^{1/2}} \tag{45}$$

where

$n\omega_1$ is the carrier
N is the sideband order.

Assuming that cyclic loading produces an increment of $\Delta\omega$ in the resonant condition of the cavity, then the sidebands produced by this frequency modulation [12] are

$$e = \sum_{n=-\infty}^{\infty} \frac{mE \sin \pi x\,(m - N) \sin (n\omega_1 + N\omega_1)t}{\pi(m - N)(mx - Nx + N)} \qquad (46)$$

where

m is modulation index $= \Delta\omega/\omega_1$
$x = \phi/2\pi$.

4) Stability

Several possible sources of instability exist in harmonic generators of this type. Lifetime of the step recovery diode will be somewhat temperature dependent and so the amplitude of the step transition may vary. Compensation for this may be accomplished by making the self-bias resistor appropriately temperature dependent and choosing an angle for transition (270°) that minimizes transition amplitude changes for small angular changes.

Another stability problem centers upon shifts in excitation frequency or cavity resonant frequency. The output frequency will always be harmonically related to the excitation frequency but its amplitude will vary with cavity drift, the more so with increasing Q.

Another, and quite different, source of instability manifests itself as grossly erratic behavior and squegging of the output signal. This effect has been observed by Boff[1] and Cutler[1] when a tuned resonant circuit is used in the excitation circuit and the cavity is tuned just below the excitation harmonic. When tuned at or above this harmonic the circuit remains quite stable. Cutler ascribes this effect to the step recovery diode introducing a level-dependent variable capacitance which, on a level-vs-frequency plot, introduces a double-valued function below resonance.

HARMONIC GENERATOR REFINEMENTS

It will frequently be required to maximize simultaneously the harmonic power and its spectral purity. It has previously been shown that the loading of the cavity by the excitation supply (particularly the intermittent component due to cyclic conduction and cutoff of the diode) can produce substantial sideband generation. This problem is accentuated when maximal harmonic power is required since coupling in of the excitation must then be tight.

Harmonic power may be prevented from reaching its ultimate possible value due to an increase in diode transition time with the increasing diode storage which is required for high-power operation. This degradation in transition time with Q is shown in (1) where it is seen that

$$T_{t_{\min}} \propto \left[\frac{(RQ)^3}{V}\right]^{2/15}. \qquad (47)$$

The increased V at higher power helps transition speed, but the associated Q increase dominates. R should be as small as possible. The resulting degradation in available harmonic power is shown in (28).

These problems can be diminished considerably with the circuit shown in Fig. 7. This configuration applies short pulses of current to the cavity. Between pulses, high source impedance is maintained. The effective source impedance (36) therefore remains much higher than would be possible with the single diode configuration discussed earlier and the influence of its cyclic variation on sideband generation diminishes because of the low duty cycle. This higher effective source impedance leads to higher power capability due to reduced loading and/or greater spectral purity.

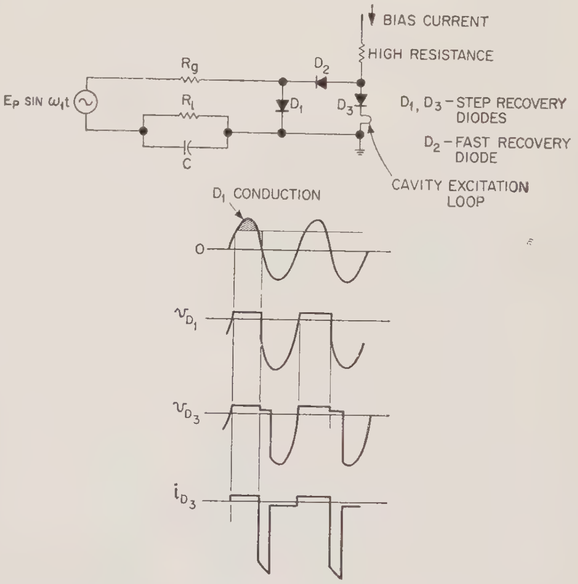

Fig. 7—Two-stage step recovery diode harmonic generator.

The transition time increase which is due to the high stored charge required for high-power operation can also be minimized with the circuit of Fig. 7. The storage requirement on the step recovery diode which forms the trailing edge of this short pulse is quite low. The trailing edge of this excitation pulse can therefore be made faster than the leading edge. If it is required, the leading edge could also be sharpened by extending this circuit to three stages.

The harmonic spectrum that results from this mode of excitation will be much less smooth than the one in Fig. 4. Peaks will occur when the harmonic period is an even multiple of the pulse width, and minima will occur at odd multiples. These maxima in harmonic excitation current can considerably exceed the corresponding amplitude produced by the single-step transition due to pulse shape, transition speed, and source impedance considerations.

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[1] Private communication.

Full-wave rectification of the excitation generator and subsequent application to a step recovery diode circuit would appear to offer some help in sideband reduction, but would not generally increase power appreciably except for very low excitation frequencies where optimum minority carrier lifetime for the diode cannot be reached.

During that portion of the cycle when both D1 and D3 are cut off, the dc bias current will flow into bias capacitor *C*, and may disturb the required self-bias. If this effect is excessive, external bias or zero bias may be required for D1.

A TYPICAL HARMONIC GENERATOR

The circuit shown in Fig. 8 demonstrates the use of the step recovery diode for harmonic generation from 0.2 to 2.0 Gc. A 50-ohm, 10-db attenuator is shown inserted between the excitation source and the harmonic generator input. This attenuator serves to establish a known source impedance for evaluation of insertion loss, and it isolates the harmonic generator from the source. This isolation diminishes undesirable interaction between the source and the nonlinear loading associated with harmonic generator action. Some freedom exists in the design of the harmonic generating circuit, which can be used for reduction of this nonlinear loading. In addition, proper design of the driver should make the attenuator unnecessary in maintaining control of the operating mode of the circuit.

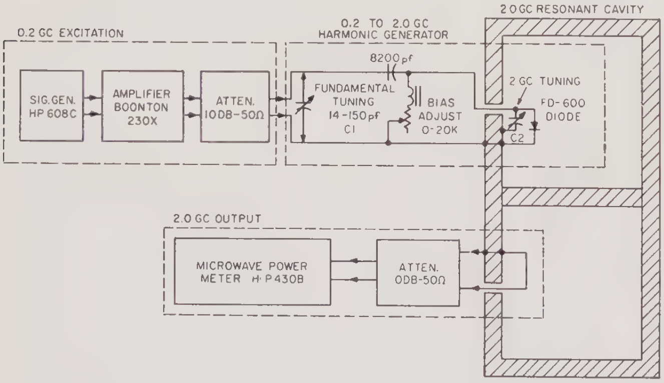


Fig. 8—A typical harmonic generator.

In order to achieve high conversion efficiency, it is desirable to establish a conjugate impedance match for fundamental frequency at the input of the harmonic generator, and a lossless load looking back from the cavity. In Fig. 8, adjustment of the value and location of C1 permits conjugate impedance match at the fundamental frequency. C2 tunes the excitation loop for peak power transfer into the cavity, and minimal transfer out. The bias adjust resistor permits the setting of self-bias for optimum output power. These adjustments are somewhat interdependent.

The step recovery diodes used for this evaluation were five Fairchild FD 600 silicon epitaxial diodes, which were selected at random from different lots. The 200-Mc source was adjusted to deliver 0.5 w into a 50-ohm load, the attenuator being considered as part of the generator.

Diode Number	2.0-Gc power into 50-Ω load	Conversion Loss
1	34 mw	11.7 db
2	46	10.4
3	70	8.5
4	56	9.5
5	60	9.2

This performance is substantially better than that achieved in one stage by conventional harmonic generators, and better than the theoretical maximum predicted by Roulston [15] for diodes of this type. The above results are not intended as indicative of the ultimate capability for this device. Efficiency could certainly have been improved by more careful circuit design and construction, and the indicated power levels were limited by the available power and not by the diode.

LIFETIME EVALUATION METHOD

An elegant technique for evaluating diode lifetime arises from these foregoing considerations. It will be seen that this method is especially useful because it permits lifetime evaluation in the sub-nanosecond range with readily available test equipment, and it avoids the customary obscuring of this measurement by diode capacitance and inductance.

The setup for this test is shown in Fig. 9(a). Sinusoidal excitation is applied to a diode and series resistor, and the diode current (resistor voltage) is observed with a sampling oscilloscope. A ballast network may be necessary to maintain more nearly uniform loading of the signal generator during the cycle and thereby minimize distortion of the excitation waveform. For optimum matching, the ballast resistor should approximate the characteristic impedance of the generator and line, and the diode load resistor R_s should be high. However, it will be seen that if R_s is too high, discrimination will be lost between storage and capacitive conduction, and the test will lose its value. Insertion loss of the ballast network must usually be minimized in order to maintain an adequate operating signal level. Some experimentation may be necessary to find an appropriate network. The excitation system shown in Fig. 8 would be generally appropriate for this test R_s will usually be the 50-ohm input impedance of the sampling oscilloscope.

Typical waveforms that are associated with this circuit are shown in Fig. 9(b). Three distinct conduction phases are apparent: forward, storage, and capacitive conduction. The peak value of forward conduction i_{pf}, as observed in the oscilloscope display of Fig. 9(b) is

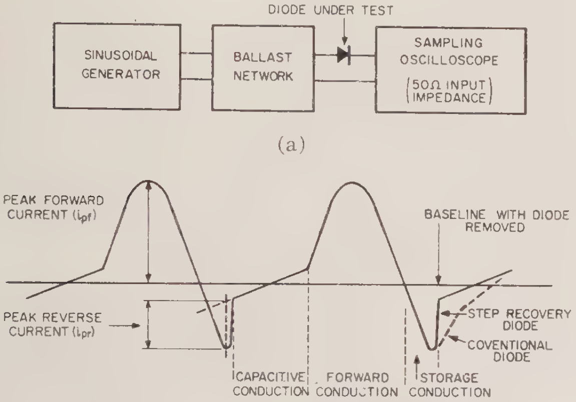
$$i_{pf} = \frac{E_p + \psi_0}{R_c} = \frac{E_p}{R_c}\left(1 - \frac{\psi_0}{E_p}\right) \tag{48}$$

where, assuming that the generator and line are matched,

$$R_c = R_s + \frac{R_b R_g}{R_b + R_g} + R_f \tag{49}$$

$$E_p = \frac{E_g\sqrt{2}R_b}{R_b + R_g}. \tag{50}$$

E_g is the rms value of generator voltage and R_g the generator impedance. These comprise the equivalent Thévenin generator for the signal source.



(a)

(b)

Fig. 9—Diode lifetime evaluation. (a) Lifetime test setup. (b) Observed waveform.

Now, interpreting Fig. 6 in terms of the present discussion, the ordinate gives the ratio of peak overshoot to E_p/R_c. This ratio is seen to be closely equal to $\omega_1\tau$ when both $\omega_1\tau$ and $\sin\theta$ are less than 0.3.

$$\omega_1\tau \approx \frac{i_{pr}}{E_p/R_c} \qquad \begin{matrix} 0 \leq \omega_1\tau \leq 0.3 \\ 0 \leq \sin\theta \leq 0.3 \end{matrix} \tag{51}$$

so

$$\omega_1\tau \approx \frac{i_{pr}}{i_{pf}}\left(1 - \frac{\psi_0}{E_p}\right) \tag{52}$$

and

$$\tau \approx \frac{i_{pr}}{i_{pf}} \frac{\left(1 - \frac{\psi_0}{E_p}\right)}{\omega_1}. \tag{53}$$

This is the result which was sought. An example will best serve to demonstrate the use of this expression. Let it be assumed that a signal source is available which will deliver 3 v into 50 ohms at 10 to 50 Mc and that the generator has a 50-ohm source impedance. The ballast network is assumed to consist of a 100-ohm resistor R_b across the line, and R_s is 50 ohms.

$$E_p = 6\sqrt{2}\left(\frac{100}{150}\right) = 5.65 \text{ volts}$$

$$\omega_1\tau = \frac{i_{pr}}{i_{pf}}(0.876).$$

In order to obtain a linear reading in the neighborhood of 1 nsec, the oscilloscope horizontal position control is adjusted so that the base line (without diode) lies along the horizontal axis. With the diode in place, oscilloscope gain is then set so that deflection associated with i_{pf} is 5 cm. Under these conditions, if 1-cm overshoot is taken to correspond to a lifetime of 1 nsec, then the appropriate excitation frequency will be

$$f = \frac{(0.876)(0.2)}{(6.28)(10^{-9})} = 27.9 \text{ Mc}.$$

This excitation frequency will give linear lifetime reading from about 0.1 to 1.5 nsec. If better resolution is required in the 0.1-nsec region, a higher excitation frequency will be required. It is important to notice, as shown in Fig. 9(b), that i_{pr} is not read from the base line but from the extrapolated capacitive conduction line, to eliminate the capacitive current contribution.

In addition to lifetime, a great deal of information about the diode is available at a glance from the representation of Fig. 9(b). Forward conductivity can be evaluated in terms of the peak forward deflection, capacitance can be evaluated from the slope of the capacitive conduction phase, and it can be seen whether transition to cutoff is fast or slow.

This test sidesteps the customary problem of establishing an operational definition for diode lifetime in the absence of a clearly defined end point, because the peak overshoot has a unique value.

CONCLUSIONS

A step recovery diode was defined as having a finite lifetime and a very rapid transition from reverse storage conduction to cutoff (reverse saturation conduction). Steady-state equilibrium conditions under sinusoidal excitation were evaluated for a conventional half-wave rectifier circuit using this diode.

The self-bias aspect of this equilibrium condition led to a generalized solution for rectification efficiency for the half-wave rectifier circuit as a function of circuit and diode parameters (including lifetime).

The transient current aspect of this circuit equilibrium was shown to lead to an equivalent Thévenin source for harmonic generation. For purposes of analysis the harmonic generator load and filter circuit were characterized in terms of input impedance and Q looking into the excitation port. Conditions for the transfer of maximum power to the load and the amount of this power were evaluated. Finally, arising out of the difficulties shown to be inherent in the half-wave configuration, an improved circuit was described which minimized most of these objections.

The step recovery diode permits generation of high powers at high harmonic orders due not only to the very rich harmonic content of its associated current or voltage, but also to the minimal loading that may be achieved of the harmonic by the excitation circuit. At high harmonic orders the equivalent harmonic current amplitude varies as the reciprocal of the harmonic order and as the amplitude of the step (multiplied by a factor related to its transition time). The source shunt impedance depends upon the duty cycle and cutoff capacitance of the diode. Preferably, these should be low.

The effective loaded Q of the filter was related to amplitude modulation and hence sideband generation. Modulation of this loading due to intermittent diode conduction produced frequency modulation and hence further sideband generation.

Arising from the foregoing dynamic equilibrium conditions, a technique was presented which permits convenient evaluation of diode lifetime in the sub-nanosecond range by considering storage conduction associated with sinusoidal excitation.

ACKNOWLEDGMENT

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Frequency Sounding Techniques for HF Communications over Auroral Zone Paths*

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Summary—This paper presents evidence that systematic oblique incidence channel sampling transmissions are valuable for improving the reliability of air-ground HF communications when propagation conditions are marginal. This evidence results from air-ground radio communications trials supplemented by frequency sounding transmissions over flight paths of up to 1260 nautical miles into auroral zone latitudes from a ground station in Nova Scotia.

The ground-air frequency sounding measurements established that propagation via clouds of auroral sporadic E was possible for a high percentage of time during geomagnetic storms. These modes provided a useful, and often the only, mode for communications over the air-ground path. In order to communicate effectively via auroral E modes, it was found necessary to use a wide selection of aeronautical frequencies. In addition, because of the rapid variation in HF propagation conditions, it was found desirable to renew channel sampling measurements once every five minutes on each frequency assignment. It was established that this procedure for the selection of operating frequencies during disturbances resulted in communications reliability that was appreciably higher than would have been obtained if other frequency selection techniques, alone, were followed.

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INTRODUCTION

MULTIFREQUENCY pulse sounding is now a commonly used HF technique for studying ionospheric propagation conditions over oblique incidence paths.[1-3] As a result of observations on operative propagation modes obtained during these studies, it has been established that there is a need to revise current methods of extrapolating vertical incidence data to propagation conditions on long HF paths. Because the multifrequency technique permits unambiguous identification of propagation modes, and indicates the frequency dependence of HF signals, it promises to be of importance in improving current methods for the prediction of optimum working frequencies (OWF).[4]

It is well known that long term predictions provide a reliable basis for the selection of operating frequencies only when propagation conditions are undisturbed. This has led a number of workers to suggest that frequency sounding techniques might be used in parallel with a communication system to determine optimum short-term communication frequencies.[5-7] If frequency sounding techniques were used as a method for systematic channel sampling, the communicator could match the operating frequencies to the propagation conditions that exist at any time on a circuit.

The attractiveness of oblique incidence frequency sounding as a short-term propagation measurement technique results from the fact that propagation conditions on any group of frequencies can be closely followed by the equipment operator, with little chance that ambiguous interpretations of observations will result. In this respect, the frequency sounding technique used for channel sampling might be expected to be more successful than back-scatter sounding techniques.[8,9] However, to date there does not appear to have been much effort devoted to establishing the value of frequency sounding for various HF communications services. This is due, in part, to lack of evidence that sounding techniques can provide suitable information that can be translated into increased communications reliability.

This paper presents evidence that systematic channel sampling can be of value for air-ground communications during marginal operating conditions. Three ground-to-air frequency sounding trials carried out in auroral zone latitudes have been selected for discussion because of their coincidence with relatively severe geomagnetic storms. The results of these trials, therefore, permit the effectiveness of systematic channel sampling to be assessed during periods of very marginal operating conditions, when normal frequency selection procedures could result in long periods of loss of radio contact.

The results reported in this paper are concerned first with observations of the occurrence and variability of F- and auroral E-layer propagation modes during geomagnetic storms. Then the use of frequency sounding equipment as a channel sampling system to select frequencies for air-ground communications is discussed. Finally, the effectiveness of frequency channel sampling, combined with a wide selection of aeronautical band frequencies, is compared with other possible frequency selection procedures.

EQUIPMENT FOR AIR-GROUND-AIR TRIALS

Frequency Sounding Equipment

The equipment used for sounding has been discussed elsewhere,[10] and it is only necessary here to outline some features of the complete system. The ground-air system used for airborne trials is illustrated in Fig. 1. A pulse sounding transmitter was situated at a field station near Halifax, Nova Scotia, and a mobile sounding receiver and associated display equipment were mounted in an Argus aircraft of the Royal Canadian Air Force Maritime Air Command. Because this aircraft can remain airborne for long periods of time, an opportunity was presented to carry out trials under various propagation conditions over periods of 10 to 20 hours.

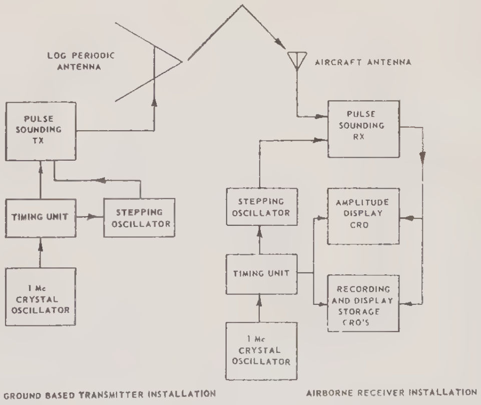

Fig. 1—Ground-air frequency sounding system.

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TABLE I

Indexes of Disturbance for Three Flight Trials in 1960

A) Mild Disturbance—Take-off 1300 GMT, November 24, Landing 0600 GMT, November 25.

	November 24				November 25	
Time Period	12–15	15–18	18–21	21–24	00–03	03–06
Magnetic Indexes, Kp	2	2	3	5	4	5
North Atlantic Quality Figures	6		5		4	

B) Severe Disturbance—Take-off 1800 GMT, November 21, Landing 1030 GMT, November 22.

	November 21		November 22			
Time Period	18–21	21–24	00–03	03–06	06–09	09–12
Magnetic Indexes, Kp	6	5	6	5	5	4
North Atlantic Quality Figures	4		4		3	

C) Severe Disturbance—Take-off 1900 GMT, December 15, Landing 1430 GMT, December 16.

	December 15		December 16				
Time Period	18–21	21–24	00–03	03–06	06–09	09–12	12–15
Magnetic Indexes, Kp	5	6	6	6	5	5	4
North Atlantic Quality Figures	3		2		4		5

The ground transmitter delivered narrow pulses of 100-kw peak power into a rotatable log-periodic antenna. The transmitter was step-tuned regularly through the HF band, in 100-kc steps, from 3 to 30 Mc, and remained on each step for one second. This program was repeated every five minutes, to provide a measure of the current state of propagation conditions on each of 270 channels separated by 100 kc. The receiver in the aircraft was similarly step-tuned through the HF band in synchronism with the sounding transmitter. A prearranged frequency-time program ensured reception of the sounding signals. To determine received signal characteristics on potential operating frequencies, the sounding signals were visually monitored on a CRT A-type display. In addition, an over-all assessment of propagation conditions across the entire band was provided by polaroid photographic records of pulse arrival time vs frequency.

This sounding equipment has been developed and used as a general purpose HF measuring instrument, and provides far more information on all frequency channels than is required to select an operating channel from one of perhaps ten assignments. The high resolution and large frequency sampling capability of this equipment have been utilized primarily to establish the active propagation modes, along with the temporal variations of the entire HF band. Moreover, the results obtained with this equipment can be used to determine characteristics of a much simpler channel sampling system that would provide propagation information on only potential operating channels.

Communications Equipment

Frequency sounding information will not be of optimum value for improving communications reliability unless two conditions on a communication system are met:

1) A sufficient number of properly spaced frequency assignments must be provided and used as required.
2) Changes in operating frequency must be made at least as fast as significant changes in propagation conditions occur.

During these trials, both conditions were satisfied. One trial frequency was selected from within almost all of the assigned aeronautical mobile bands, from 3 to 23 Mc, and fast frequency-changing transceivers were used in the aircraft. In this manner, a serious attempt was made to effectively match the air-ground traffic frequencies to those that were optimum for the propagation conditions that existed at any particular time on the path between the aircraft and the ground station. Because sounding information was provided only in the aircraft, it was also necessary to ensure that a continuous watch was maintained on all trial frequencies at a ground communications station near the sounding transmitter location.

Observations During Trials

Because of their relationship to the results of these trials, the magnetic indexes (Kp) and the North Atlantic Quality Figures (NAQF) for the three trial periods to be described are presented in Table I. From the values of Kp and NAQF, HF propagation in auroral zone latitudes could be expected to be disturbed ($Kp \geq 4$) for many periods during the three flights, which all took place during a recurring series of severe ionospheric storms in November and December, 1960.

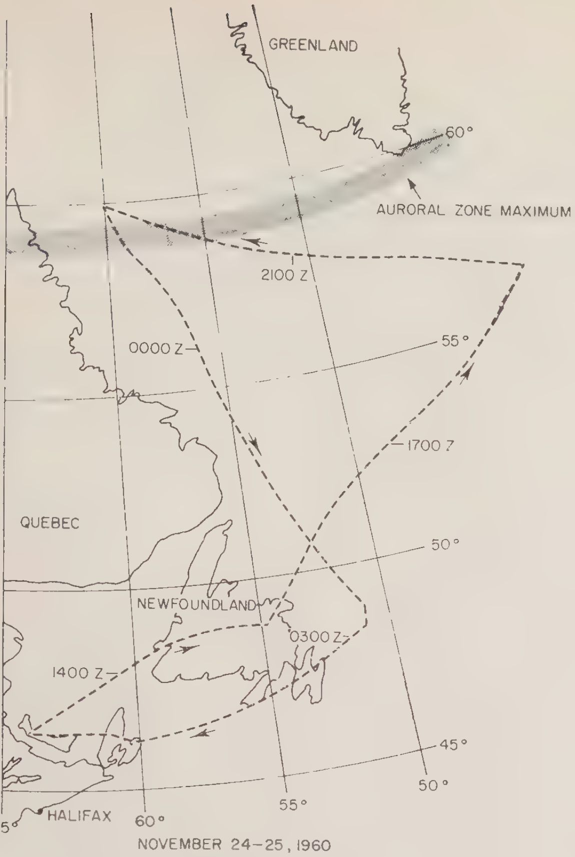

Fig. 2—Flight plan for ground-air trials, November 24–25, 1960.

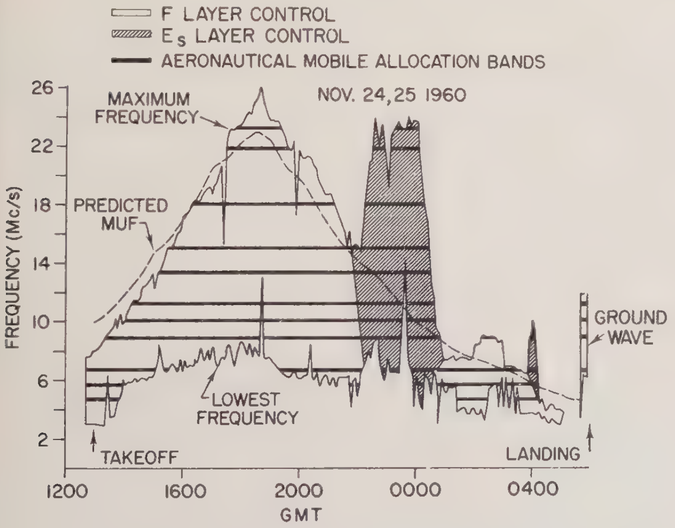

Fig. 3—The maximum and lowest frequencies observed with the airborne sounding equipment, November 24–25, 1960.

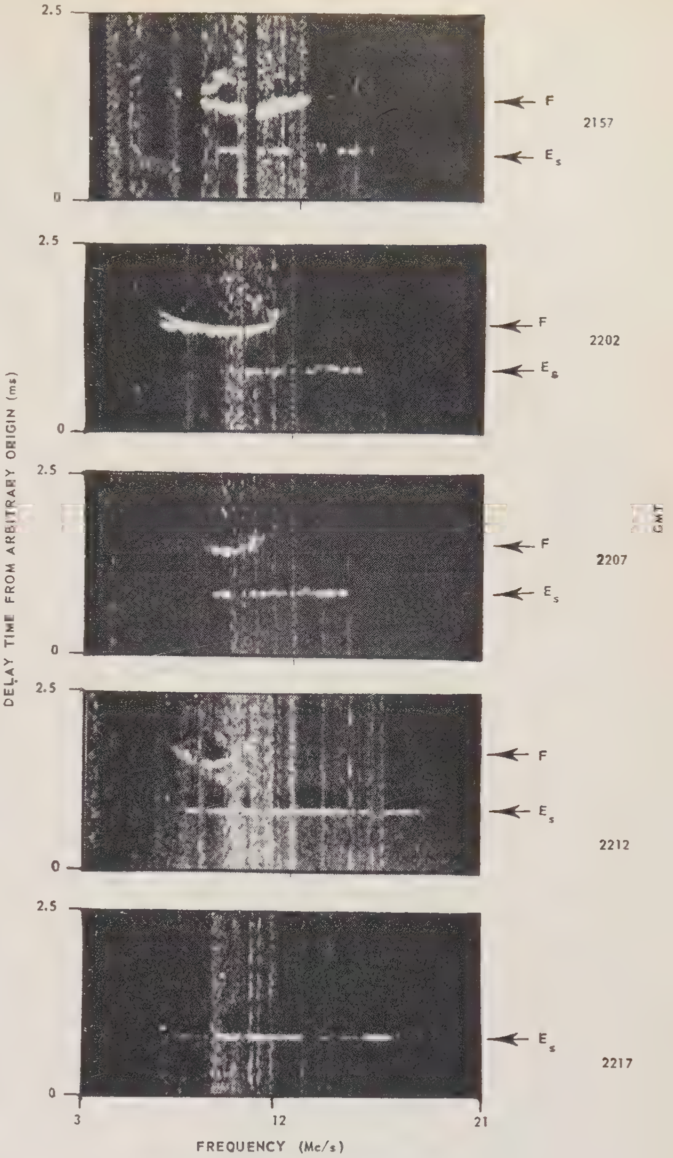

Fig. 4—Oblique ionograms to illustrate the blanketing of the one hop F mode by the one hop auroral sporadic E mode 2157–2217 GMT, November 24, 1960.

HF Propagation During a Mild Geomagnetic Disturbance

Fig. 2 shows the path followed by the aircraft during the November 24–25 flight trial, into areas south of Greenland at a maximum distance of 1130 nautical miles NE of the ground sounding station. The maximum and lowest frequencies observed with the sounding equipment are presented in Fig. 3. Also shown are periods in which the aeronautical bands from 3 to 23 Mc lay between the maximum and lowest frequency. The predicted maximum frequency (MUF), based on Canadian prediction tables,[11] provided an accurate measure of the maximum frequency on the ground-air path, except for periods after 2200 GMT.

A mild geomagnetic disturbance is indicated by the presence during the flight of blanketing auroral sporadic E from 2200 to 0100 GMT, and for a further short period later. This was followed by a complete HF blackout period shortly before landing. Detailed observations of the progressive blanketing of the one-hop F mode between 2157 and 2217 GMT by one-hop auroral E transmission are shown in Fig. 4 as a series of oblique ionograms. The changes in F-layer multipath structure, the maximum frequency, and the lowest frequency observed in this period are representative of the rapid variations of HF signal structure that occur during geomagnetic storms in auroral zone latitudes.

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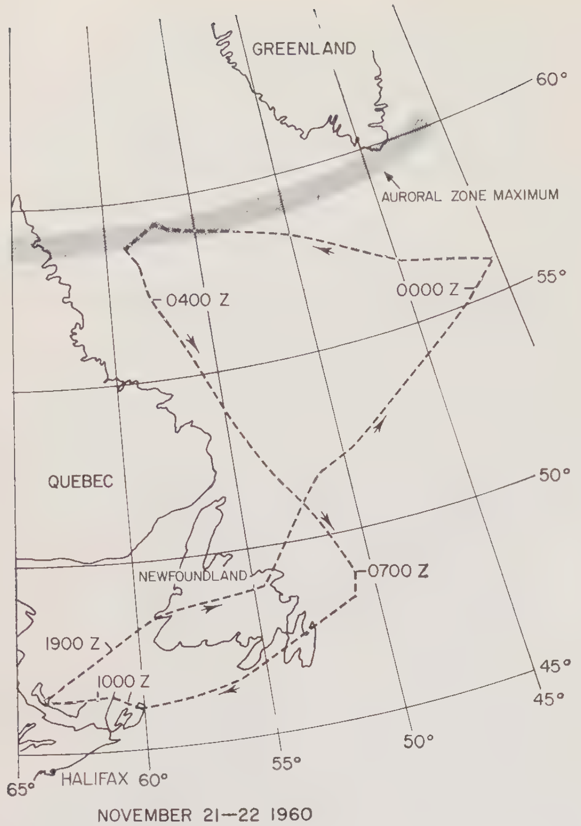

GREENLAND
60°
AURORAL ZONE MAXIMUM
55°
0400 Z
0000 Z
QUEBEC
50°
NEWFOUNDLAND
0700 Z
1900 Z
1000 Z
45°
45°
50°
55°
65°
HALIFAX
60°
NOVEMBER 21—22 1960

Fig. 5—Flight plan for ground-air trials, November 21–22, 1960.

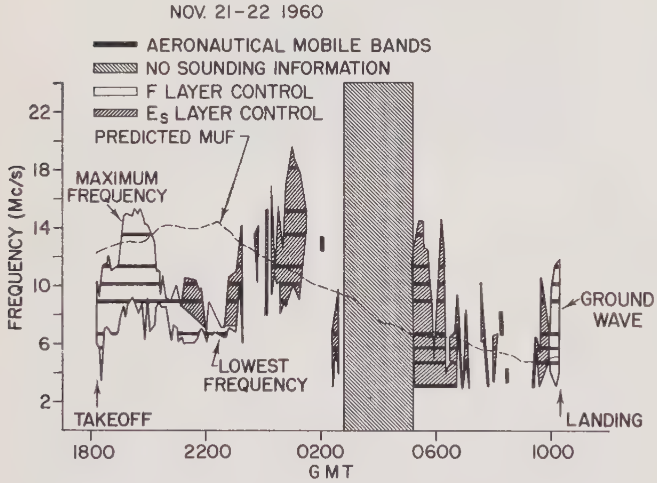


Fig. 6—The maximum and lowest frequencies observed with the airborne sounding equipment, November 21–22, 1960.

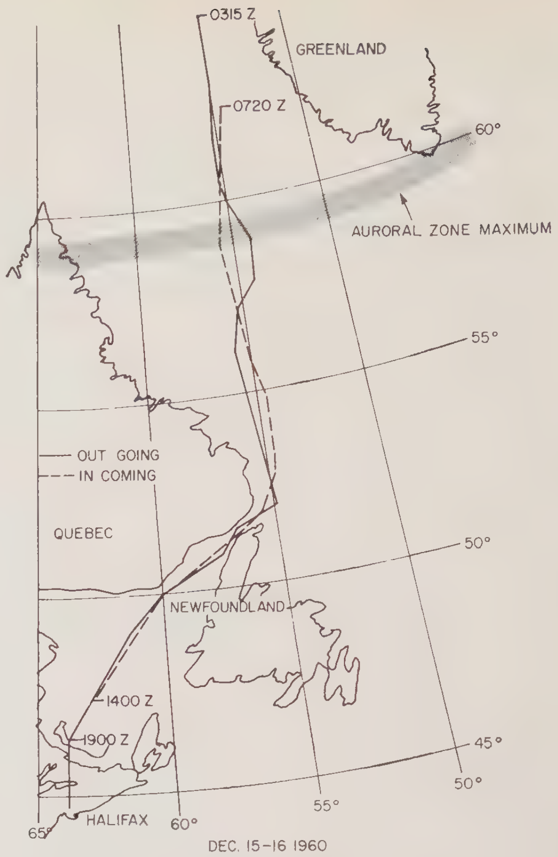
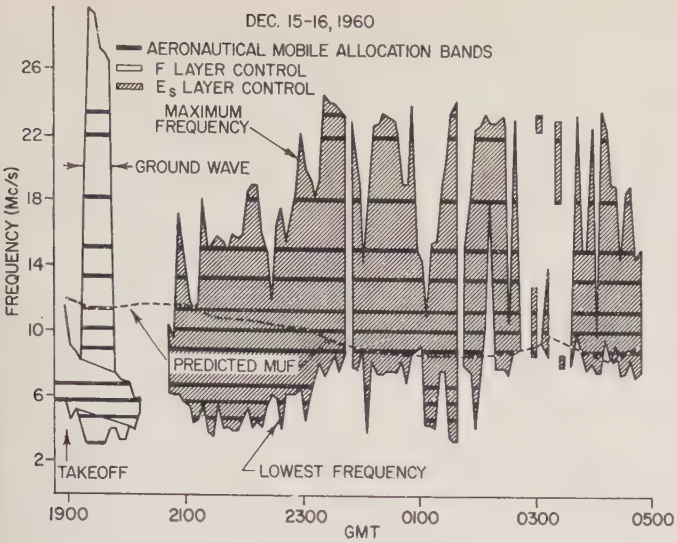

0315 Z
GREENLAND
0720 Z
60°
AURORAL ZONE MAXIMUM
55°
OUT GOING
IN COMING
QUEBEC
50°
NEWFOUNDLAND
1400 Z
1900 Z
45°
50°
55°
65°
HALIFAX
60°
DEC. 15-16 1960

Fig. 7—Flight plan for ground-air trials, December 15–16, 1960.

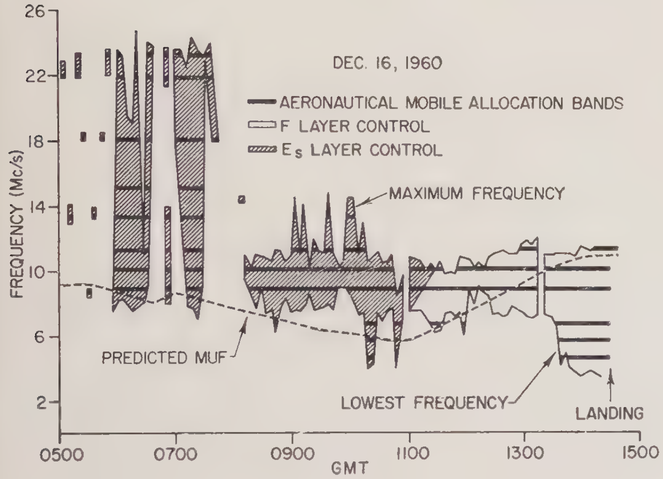
HF Propagation During Severe Disturbances

Fig. 5 shows the flight path for a trial (November 21–22, 1960) in the same areas illustrated in Fig. 2. The propagation conditions during most of this flight period were severely disturbed, as shown in Fig. 6. The maximum frequency of the F-layer modes dropped rapidly after 2000 GMT and auroral sporadic E clouds provided the only propagation mode for the greater part of the flight. As a consequence, predictions of maximum frequencies, based on F-layer transmission, were of very limited value for the entire period. The sporadic E clouds persisted for several minutes to hours and alternated with periods of complete HF blackout. (Between 0230 and 0515 GMT, no sounding information was recorded in the aircraft due to an equipment malfunction.)

The characteristics of auroral sporadic E were confirmed in a later flight (December 15–16, 1960) to 65°N on the 55°W meridian, illustrated in Fig. 7. The aircraft remained at ranges between 1100 and 1260 nautical miles from the ground station for four hours before returning to base. A geomagnetic storm commenced at 0700 GMT, December 15, and values of $Kp \geq 4$ and low NAQF were recorded for over 24 hours (Table I). The observed propagation conditions during the flight period (Fig. 8) illustrate the severity of the storm in auroral zone latitudes. Shortly after take-off, and beyond the range of ground wave, the entire HF band was blacked out. Sporadic E clouds then provided the only propagation mode on the air-ground path for the remainder of the outgoing leg of the flight [Fig. 8(a)]. During the return leg [Fig. 8(b)] sporadic E continued to provide a variable, but useful, mode until 1030 GMT. During periods of either sporadic E- or F-layer control of the path MUF, the predictions of maximum frequencies were of little value in the selection of communications frequencies.



(a)



(b)

Fig. 8—The maximum and lowest frequencies observed with the airborne sounding equipment, December 15–16, 1960. (a) Outgoing leg of the flight. (b) Incoming leg of the flight.

Discussion

Communications Using Auroral Sporadic E

Inspection of Figs. 3, 6 and 8 reveals that the extent of the useful HF band was often very limited indeed, and important variations in the maximum and lowest frequencies occurred in intervals of less than 15 minutes. During the most disturbed periods, the effective utilization of available modes appears to present problems both in the selection of suitable communications frequencies and in passing an acceptable volume of traffic. However, the observations establish that the twelve aeronautical bands provided adequate resolution in frequency to cover almost all sporadic E frequency bands, however narrow, between 3 and 23 Mc. Frequency sounding information on other frequency bands was redundant during these trials.

During some periods of high absorption, only one or two aeronautical bands were useful for communication. These periods of very limited HF propagation were operationally important, since long outage times would have resulted if communications had not been carried out in these bands during the short time that they could support transmissions. In some cases, the time available for selecting frequencies and passing traffic was less than ten minutes. On the other hand, during periods in which the auroral E clouds persisted for several hours, no particular urgency in passing traffic was necessary, provided the operating frequency was selected in the middle of the useful HF band. This band was often well above normal operating frequencies during the night.

During the trial periods, the radio operator in the aircraft carried out air-ground-air communications checks on frequency bands selected from sounding information. These communications confirmed that selection of operating frequencies based on the pulse sounding technique leads to a high percentage of successful communications. When HF absorption was high, discrepancies occasionally arose between sounding observations and communications reliability. The occurrence of high interference levels on assignments, and some differences in system gains between communications and sounding equipment, accounted for most of these discrepancies.

Frequency Usage Plans and Communications Outage Times

The observations obtained during disturbances indicate that the use of a high channel sampling rate combined with a wide selection of operating frequencies is a useful operating procedure. It is worth considering here the deterioration in performance that would have resulted if other frequency plans, not well matched to the changing propagation conditions, had been used.

It is apparent, first, that considerable sacrifice in reliability would have resulted if assignments in only a limited number of aeronautical bands had been available, and used on either a prearranged or hunt-and-try basis. Moreover, if the frequencies had been selected from predictions of optimum working frequencies, long outages would have resulted during severe disturbances. One possible compromise plan, that provides for the determination of optimum operating frequencies once per hour, rather than once every five minutes, might be considered.

To illustrate the use of this frequency selection procedure, and for the purpose of calculation, let it be assumed that assignments in two aeronautical bands are selected at the beginning of each hour from channel sampling information provided in the aircraft. These two assignments would then be used for air-ground-air communications for the hour. This results in a simple procedure for channel sampling, and only two frequencies would need to be monitored each hour rather than frequencies in most of the aeronautical bands. In Figs. 9 and 10 the communications outages that result from this method of selecting and using frequencies are compared with other frequency selection methods for the

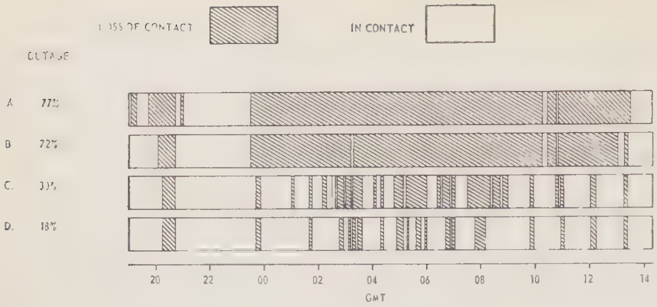


Fig. 9—Durations of loss of radio contact, December 15–16, 1960. A. Predictions—using a frequency in the band closest to the OWF. B. Predictions—using frequencies in two bands closest to the OWF. C. Channel sampling—using frequencies in two bands selected each hour. D. Channel sampling—using frequencies in all aeronautical bands as required.

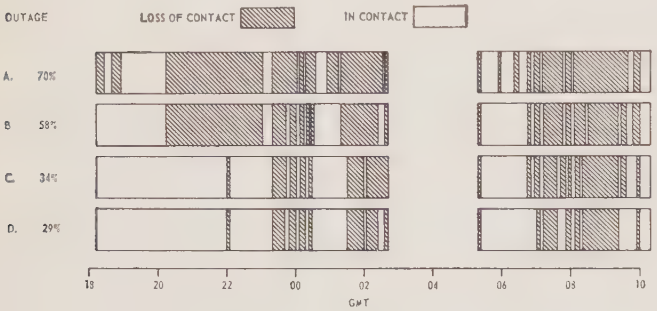


Fig. 10—Durations of loss of radio contact, November 21–22, 1960. A. Predictions—using a frequency in the band closest to the OWF. B. Predictions—using frequencies in two bands closest to the OWF. C. Channel sampling—using frequencies in two bands selected each hour. D. Channel sampling—using frequencies in all aeronautical bands as required.

severe disturbances of November 21–22 and December 15–16, respectively.

The outage periods based on the use of long-term predictions are shown opposite method A (using only frequencies in the aeronautical band closest to the predicted OWF) and method B (using frequencies in two aeronautical bands closest to the predicted OWF). For both the A and B methods of selecting frequencies, the outage times are so excessive that the radio operators would have rejected prediction maps and resorted to other methods for determining operating frequencies. By way of comparison, method C (using frequencies in two bands selected each hour) shows the much lower outages that would result by improved matching of communications frequencies to propagation conditions. Finally, method D (using frequencies in all bands as required, and sampling on each band every five minutes) leads to still further improvement. For the November 21–22 trials, outages of 34 per cent, using five frequencies (method C), are reduced to 29 per cent, again using five frequencies (method D). The corresponding outages for the December 15–16 trials are 30 per cent, using five frequencies (method C), and 18 per cent, using six frequencies (method D).

Although the compromise plan offers the advantages of simplified channel sampling and operating procedures during disturbances of this sort, it is not as effective as the method of channel sampling at intervals of five minutes to provide information from which optimum communication frequencies from all bands can be selected as required.

CONCLUSIONS

During three geomagnetic storms in auroral zone latitudes, auroral sporadic E clouds occurred for a high percentage of time. These clouds provided a useful, and often the only, mode for extended range HF transmission. To match communications operating procedures to the highly variable characteristics of auroral E- and disturbed F-layer propagation, it was necessary to provide a well-spaced selection of assignments. Also, some method for effective selection of operating frequencies, using frequency sounding techniques (or some form of systematic channel sampling), was required. Finally, because the reception quality on operating frequencies often changed rapidly during periods of less than 15 minutes, it was necessary to sample the propagation conditions on available assignments more frequently than once per hour, as well as to pass traffic with a minimum of delay. The propagation outage times which occurred when these procedures were followed were significantly lower than would have been obtained with other possible frequency usage plans not matched to the propagation conditions.

It must be emphasized that the actual improvements that might be achieved when channel sampling combined with wide selection of operating frequencies is used, depend very much on the characteristics of the HF circuit. The results discussed in this paper apply particularly to paths less than 2200 km in length, the limiting range for one-hop sporadic E transmission. Moreover, the transmission paths during the tests were near or through the zone of maximum auroral activity, and auroral sporadic E occurrences are known to have a strong geomagnetic latitude dependence.

However, for any transmission path, optimum frequencies can be determined by some technique for channel sampling. If optimum frequencies for particular paths are used by circuit operators, not only will the best signal levels be achieved, but also, the congestion that results from many transmissions on frequencies towards the low end of the HF band should be reduced. This congestion will be of particular concern during periods of low sunspot numbers and as traffic in the HF band increases.

ACKNOWLEDGMENT

The authors wish to acknowledge the interest and support of the RCAF air and ground personnel who participated in these trials. They would also like to acknowledge the contribution of the EMI-Cossor Electronics personnel who constructed the airborne equipment and operated the pulse transmitter at the DRTE Field Station near Halifax, Nova Scotia, during the trials.

Correspondence

Traveling-Wave Tube with 1.7 db Noise Figure in L Band*

During recent months work has been carried out at Watkins-Johnson Company to investigate the effect of helix attenuation on traveling-wave tube noise figure. The experimental work has consisted of measuring noise figure on various low-noise tubes while refrigerating them with liquid nitrogen, and was described at the 1961 Electron Devices Meeting in Washington, D. C.[1] The purpose of this communication is to report the most significant result of these tests, namely, the achievement of a noise figure of 1.7 db in L band, as measured at the input terminal.

This observation was made with a WJ-226 low-noise tube, designed to operate from 1.4 to 2.3 Gc. It employs a multi-electrode low-noise gun with the beam-forming anode operated at about 3 volts positive with respect to the cathode. The electron beam is hollow, being drawn from an annular cathode. Principal operating and design parameters of the tube are summarized below:

Beam current	55 μa
Helix voltage	135 v
Helix TPI	130
Helix ID	0.090 in
Wire diameter	0.004 in
γa (at 1.6 Gc)	1.7
Cathode OD	0.050 in
Cathode ID	0.040 in
Magnetic field	1000 gauss
Gain	32 db

The frequency dependence of noise figure for this tube, with all voltages fixed, is shown in the upper curve of Fig. 1. Focusing field for this case was 1000 gauss. The lowest value obtained under conditions of room-temperature ambient was 2.6 db, at 1.575 Gc. With the tube (and solenoid) immersed in liquid nitrogen, the performance indicated by the lower curve was obtained. This curve was run with a field of 1140 gauss, and shows a low value of 1.9 db. On increasing the field to 4500 gauss, the noise figure reached its lowest value of 1.7 db. At the conclusion of the low-temperature test the nitrogen was allowed to evaporate with no change being made in the set up. Fourteen hours later, with thermal equilibrium established at room temperature, the noise figure at 1.65 Gc was again measured and found to be just over 3.0 db with all operating conditions duplicating those which had resulted in 1.9 db at low temperature.

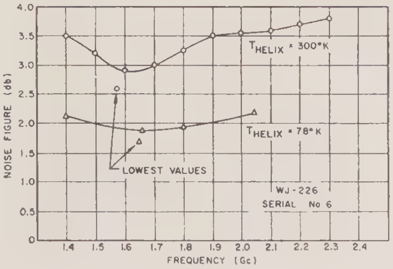


Fig. 1—Broad-band terminal noise figure at room-temperature ambient and with tube immersed in liquid nitrogen for tube WJ-226, Serial No. 6. The lowest value reached was 1.7 db, at a frequency of 1.65 Gc.

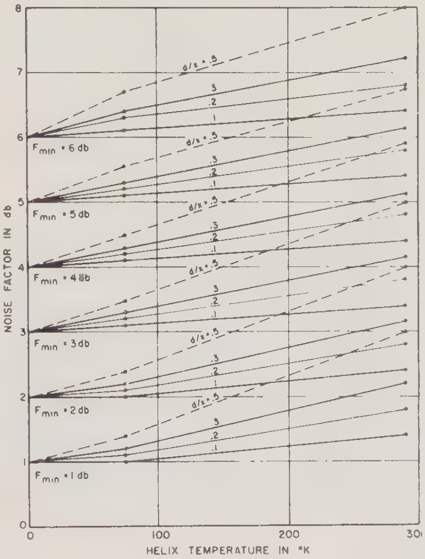


Fig. 2—Traveling-wave tube noise figure as a function of helix temperature. Families of curves are shown for different minimum noise figures, $F_{\min}$, and different loss-to-gain parameters, d/x_1 (value for room temperature).

An additional test using a different tube of the same type, but with a probe electrode centered in the hollow cathode, yielded closely similar results. In this instance, rather than immersing both tube and solenoid, liquid nitrogen was poured into a hole in the heat-insulated tube capsule, which remained in a horizontal position. Again, both the helix and the input line and transducer were subjected to cooling. Noise figure was reduced from 3.1 db to 2.2 db, at a frequency of 1.51 Gc and with magnetic field remaining constant at 1000 gauss.

The reduction in noise figure obtained by refrigerating the tube is ascribed principally to the following:

1. Reduction of thermal noise power generated by the helix by lowering both its temperature and attenuation.
2. Lowering of input dissipation losses.

Theories explaining the first of these effects have been carried out by Bloom[2] and by Israelsen.[1] The result is contained in the following expression for noise figure:

$$F = F_{\min} + d/x_1\left[\xi + \frac{T_h}{T_0}\right]$$

where

$$F_{\min} = 1 + \xi$$
$$= 1 + R\sqrt{4-\pi}\,\frac{T_c}{T_0} \quad \text{(lossless helix)} \qquad (1)$$

R is the noise reduction factor
$d/x_1 = d(T_h)/x_1(T_0)$ is the helix cold-loss-to-hot-gain ratio
T_c is cathode temperature
T_h is helix temperature
$T_0 = 290°K$

In the tube used in the first test described above, measurements of helix attenuation at liquid nitrogen temperature showed it to range between 35 per cent and 40 per cent of the room-temperature value over the band 1.5 to 1.9 Gc. On this basis, (1) predicts a decrease in noise figure of 0.5 db, about 80 per cent of which is attributable to the reduced attenuation, and 20 per cent to the lower temperature. The measured reduction was about 1 db. Of the half db difference, 0.25 to 0.3 db is due to the reduced dissipation loss in the input line and coupler, and the remaining 0.2 db is attributed to mismatch and reflection effects at the couplers and mid-section attenuator.

Fig. 2 shows the noise figure reduction to be expected from helix refrigeration for a number of different values of d/x_1 and of $F_{\min}$. These curves are simply plots of (1), with helix temperature as the independent parameter. It is evident that the noise reduction effect becomes more prominent, the lower $F_{\min}$ (as in the experiments cited) or the higher d/x_1 (such as in a millimeter-wave traveling-wave tube or in a narrow-band filter-helix traveling-wave tube). In a practical situation the noise reduction would be even greater than that shown because of input coupler cooling.

Compact and self-contained liquid nitrogen refrigerators make helix cooling a practical possibility. A cooled-helix traveling-wave tube might, for example, be used as a second-stage preamplifier following a maser amplifier, where liquid nitrogen or helium is already present. In less demanding applications, Peltier cooling might be used to cool the helix to about 200°K. For a very low $F_{\min}$ and high d/x_1 (such as in a narrow-band band filter-helix traveling-wave tube with high circuit impedance) this type of electronic cooling could well be practicable. Additional novel possibilities would be opened by cooling a helix with liquid helium into the superconducting realm. Besides yielding the lowest possible circuit loss, a superconducting helix could conduct the current to provide its own beam-focusing magnetic field.

Valuable assistance in performing the low-temperature noise figure tests was rendered by F. T. Mauch.

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[1] B. P. Israelsen, "The effect of helix loss on noise figure in traveling-wave tubes," IRE Trans. on Electron Devices, vol. ED-9, pp. 217–221; March, 1962.

[2] S. Bloom, "Effect of distributed-loss noise generators on traveling-wave tube noise factor," *RCA Rev.*, vol. 22, pp. 347–349; June, 1961.

Emission Patterns of a Ruby Laser*

In order to study the nature and manner of activation of the so-called filamentary modes of ruby laser crystals, a program of high speed photography[1,2] has been in progress at the Naval Ordnance Laboratory. Using a Beckman-Whitley Model 192 High Speed Framing Camera,[3] several crystals have been photographed at framing rates of about 500,000 per second with exposure times of about $\frac{2}{3}$ μsec. A total of 82 sequential frames are obtained each time the laser is activated. Many of these are blank if the laser stimulation is not far above threshold as the camera cannot be synchronized with the random bursts of light.

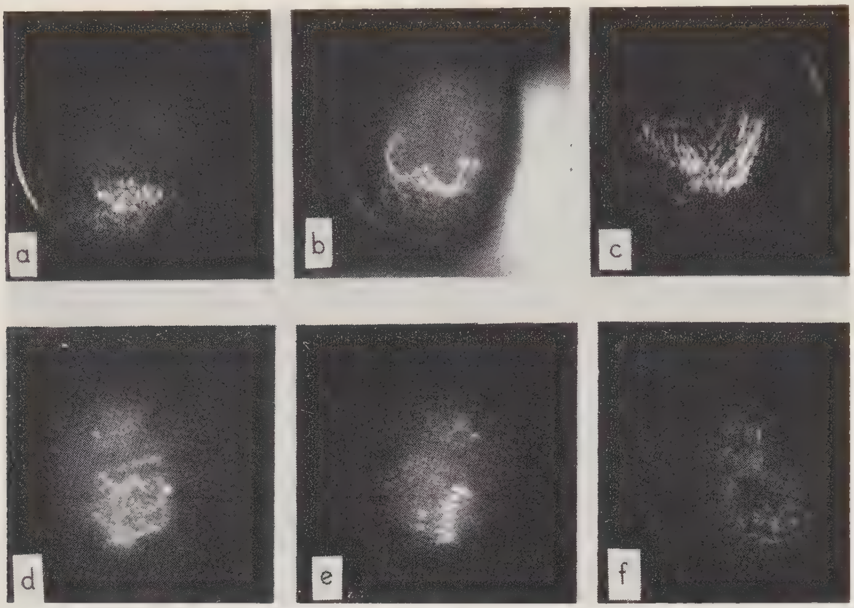

Fig. 1—End views of ruby crystals emitting laser light. Pump light leaking around crystal holder outlines the crystal face and illuminates the fine scratches on the crystal surface. Note presence of both coarse and fine grained patterns simultaneously in different parts of crystals.

Figs. 1(a) and (b) were selected from a sequence of photographs as representative of a kind of transverse mode pattern frequently seen in our crystals. This crystal was $\frac{1}{4}$ inch in diameter, 2 inches long, had polished sides and, according to the manufacturer, had ends flat to 0.1 wavelength and parallel to 6 seconds of arc. Its c axis was oriented perpendicular to the rod axis. It had uniform multiple layer dielectric coatings covering both its ends. The patterns shown in Figs. 1(a) and (b) were obtained with the camera focussed on the end of the crystal, using an auxiliary lens to increase the final image size. In our arrangement it is possible for an aperture stop to shadow the collimated light from part of the object while letting noncollimated light pass. This is the reason no laser light is seen for $\frac{2}{3}$ of the crystal in Fig. 1(a). These patterns seldom last even for a 2-μsec interval. Generically similar patterns recur frequently after an interval of roughly 10 μsec. They occur at all pumping levels and seem to recur in the same part of the crystal, although several parts of a crystal may give such geometric patterns, sometimes at the same instant of time. Fig. 1(c) show a pattern of a different sort frequently observed in this crystal.

In Fig. 1(d) and (e) we show some patterns obtained in a highly annealed crystal of the same shape having its c axis perpendicular to the rod axis. This crystal was obtained from the same source as the previous crystal and is said to have the same dimensional tolerances. The geometric patterns are generally less sharply developed and are accompanied by more randomness. The sharply defined arcs seen with the first crystal seem more diffuse in this one.

Finally for comparison we show in Fig. 1(f) a selected photograph from a crystal of similar shape having 0.05 per cent chromium with sides ground but not polished, and with ends polished to less strict tolerances since this crystal was manufactured a year ago. This crystal had silvered ends with less than 1 per cent light transmission, and the c axis was parallel to the bar axis. This crystal exhibited much more randomness in its light patterns, the one chosen for the photograph being selected for a maximum amount of apparent interference fringe effects. Some arc-like components of the light pattern can be seen.

In general, an examination of these, and others of the more than 6000 similar photos made at the Naval Ordnance Laboratory, suggests that the geometric patterns obtained are the transverse distributions of the normal modes of electromagnetic oscillation of "filamentary" active regions. The other parts of the crystal produce modes of a more random appearance. We have not found transition regions where the sizes of the emitting source patches vary continuously from the large size characteristic of the geometric patterns to the small size characteristic of the random patterns. A third kind of pattern is characterized by sweeping arcs such as in Fig. 1(c). This type of mode has a sort of cloudy appearance on the photographs and tends to persist for several microseconds with what appears to be a sweeping motion.

The author wishes to express his thanks to B. V. Kessler who did most of the work of taking the photographs, and to B. J. Crapo and Dr. T. Marshall for having made the camera available for this work.

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* Received March 14, 1962; revised manuscript received April 12, 1962.

[1] A preliminary account of some of those observations was presented in the Supplementary Programme at the June, 1961, Joint Meeting of the American and Mexican Physical Societies, Mexico City, by E. S. Dayhoff and B. V. Kessler. For some sequence photographs of one crystal [seen here in Fig. 1(f)] see E. S. Dayhoff and B. V. Kessler, "High speed sequence photography of a ruby laser," *Appl. Optics*, vol. 1, pp. 339–341; May, 1962.

[2] High speed photographs of a ruby laser have been published by J. C. Borie, M. Durand and A. Orszag, "Photographie ultrarapide de la face de sortie d'un cristal de rubis fournissant l'émission 'laser,'" *Compt. Rend.*, Paris, vol. 253, pp. 2215–2217; November 13, 1961. See also G. L. Clark, R. F. Wuerker, and C. M. York, "High-speed photographic study of ruby laser emissions," *J. Opt. Soc. Am.*, vol. 51, p. 1468; December, 1961.

[3] A description has been given by M. C. Kurtz, "A new framing camera," *J. SMPTE*, vol. 68, pp. 16–18; January, 1959.

The Efficiency of Bulk Rectification*

It is possible to "rectify" in a nonlinear bilateral isotropic bulk material. The "rectification" is accomplished by applying a zero-average nonsymmetric waveform to a bulk material having a symmetrically (with respect to the origin) nonlinear volt-ampere characteristic. Bridges[1] pointed out this possibility for obtaining dc from waveforms which themselves contained no dc and called the technique pseudorectification. This note reports an investigation of the theoretical efficiency of the technique.

By means of pseudorectification some of the energy contained in a periodic waveform (of period T) which lacks half-wave symmetry $[f(t) \neq -f(t+T/2)]$ is converted to dc when the waveform is applied to a resistive element having a volt-ampere characteristic of the form shown in Fig. 1. Functions of the type shown in Fig. 1 can be expressed mathematically as $i = K\,[\operatorname{sgn}(e)]\,|e|^n$ where sgn is a function having unity amplitude and the sign of its argument. Nonlinearities of this type are readily available in the form of silicon carbide varistors which n between 2 and about 7.

The process of pseudorectification is demonstrated by considering a nonlinearity of the type shown in Fig. 1 with $n=3$. It is excited by a voltage source (shown in Fig. 2)

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* Received April 5, 1962. This work was supported by Air Force Systems Command, Wright-Patterson AF Base, Dayton, Ohio, under Contract No. AF 33(616)-7355.

[1] J. E. Bridges, "Pseudo-rectification and detection by simple bilateral nonlinear resistors," Proc. IRE, vol. 49, pp. 469–478; February, 1961.

of the form $e_s(t)=E\cos\omega t+E\cos 2\omega t$. The resultant current is then given by

$$i(t) = K(E\cos\omega t + E\cos 2\omega t)^3. \qquad (1)$$

The sgn function is no longer needed since a change in sign of $e(t)$ is reflected in a change in sign of $i(t)$ for odd exponents. Expanding and collecting terms one obtains

$$\begin{aligned} i(t) = KE^3[&3/4 + 9/4\cos\omega t + 9/4\cos 2\omega t \\ &+ \cos 3\omega t + 3/4\cos 4\omega t + 3/4\cos 5\omega t \\ &+ 1/4\cos 6\omega t]. \end{aligned} \qquad (2)$$

It is noted that a dc current of $\frac{3}{4}\,KE^3$ amperes results from applying the waveform of Fig. 2 to the symmetrical nonlinearity. Alternately, if a nonsymmetrical current source had been applied to the nonlinearity, an average value of voltage would have resulted. The physical reason for the average value in each case is clearly the nonlinear weighting of amplitudes. Hence, in the case of voltage excitation the average value in the excitation waveform is zero. but since the amplitude of the voltage waveform is different in the positive and negative portions of the cycle and since the current is a cubic weighting of the instantaneous amplitude, the weighted waveform has a nonzero average value.

Although the above explanation is adequate to describe the mechanism by which the conversion from ac to dc is accomplished it gives no information about dc output power. In order to obtain usable output power a circuit of the form shown in Fig. 3 is assumed.

A large capacitance C has been placed across R_L to insure that only dc power is extracted from the circuit by the load resistor. Since the R_L-C combination is assumed to have a dc voltage across it, it can be replaced by a dc source for purposes of calculation. This gives $e_s(t)-e_{dc}$ as the voltage applied to the nonlinear resistance. Using this voltage the current is recalculated as

$$i(t) = K[e_s(t) - e_{dc}]^3$$

or

$$i(t) = K(-e_{dc} + E\cos\omega t + E\cos 2\omega t)^3$$

and letting $e_{dc}/E=b$, $i(t)$ becomes

$$i(t) = KE^3(-b + \cos\omega t + \cos 2\omega t)^3. \qquad (3)$$

Again expanding and collecting terms and retaining only the dc term and the first and second harmonics, one obtains the expression

$$\begin{aligned} i(t) = KE^3[&(3/4 - 3b - b^3) \\ &+ (9/4 + 3b^2 - 3b)\cos\omega t \\ &+ (9/4 + 3b^2 - 3/2b)\cos 2\omega t + \cdots]. \end{aligned} \qquad (4)$$

(The other currents do not enter into the power exchange relations.)

Average input power is then given by

$$\begin{aligned} P_{in} = &\frac{KE^3}{2}\left(\frac{9}{4} + 3b^2 - 3b\right) \\ &+ \frac{KE^3}{2}\left(\frac{9}{4} + 3b^2 - \frac{3}{2}b\right)E \end{aligned} \qquad (5)$$

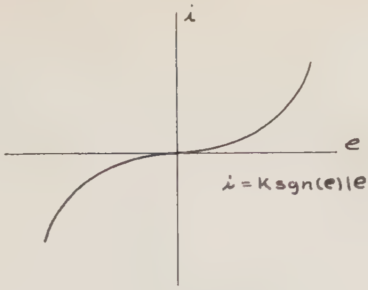

Fig. 1—General symmetrical nonlinearity.

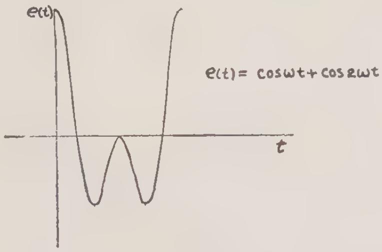

Fig. 2—A waveform lacking half-wave symmetry.

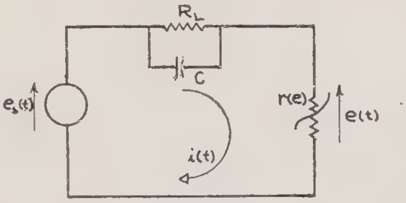

Fig. 3—Nonlinear with linear load.

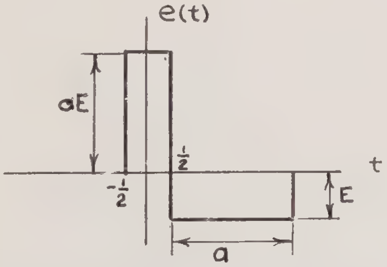

Fig. 4—A zero average nonsymmetrical wave.

and average output power (*i.e.*, power delivered to e_{dc}) is given by

$$P_0 = bKE^3(\tfrac{3}{4} - 3b - b^3). \qquad (6)$$

Using (5) and (6) the efficiency of conversion is obtained as

$$\eta = \frac{\frac{3}{4}b - 3b^2 - b^4}{3b^2 - \frac{9}{4}b + \frac{9}{4}} \times 100\%. \qquad (7)$$

If the maximum η as a function of b is sought (by long hand or by computer) one obtains $\eta=2.82$ per cent at $b=0.124$. Therefore, $e_{dc}=0.124E$ and $I_{dc}=KE^3\,(0.376)$. The value of R_L necessary to obtain this maximum efficiency is found to be

$$R_L = \frac{0.124E}{KE^3(0.376)} = \frac{0.33}{KE^2}. \qquad (8)$$

If n is increased to 5 a similar calculation yields

$$\eta_{max} = 5.03 \quad \text{at} \quad b = 0.18$$

and

$$R_L = \frac{0.140}{KE^4}.$$

It is difficult to carry out the algebraic manipulations associated with this method of solution for $n>5$ so a different type of waveform is considered, namely, the nonsymmetrical pulse shown in Fig. 4.

It is helpful to compare the waveform of Fig. 4 with the previous excitation by calculating its harmonic content. Taking the Fourier series the familiar result

$$i(t) = bo + \sum_{k=1}^{\infty} b_k \cos\left(\frac{2k\pi t}{a+1}\right)$$

where

$$bo = 0$$

and

$$b_k = \frac{2E(a+1)}{k\pi}\sin\left(\frac{k\pi}{aH}\right). \qquad (9)$$

is obtained.

This expression is essentially a sin x/x function. Therefore, for k small and "a" large "a" is a measure of the number of approximately-equal-amplitude harmonics.

Replacing $e_s(t)$ in Fig. 3 by

$$e(t) = \begin{cases} aE - e_{dc} & -1/2 \le t < 1/2 \\ -E - e_{dc} & 1/2 \le t < 1/2 + a \end{cases} \qquad (10)$$

and using the general expression

$$i(t) = Ke(t)^n \ (n \text{ odd})$$

one obtains

$$i(t) = \begin{cases} K(aE - e_{dc})^n & -1/2 \le t < 1/2 \\ K(-E - e_{dc})^n & 1/2 \le t < 1/2 + a. \end{cases} \qquad (11)$$

Using (10) and (11) the total input power and total output power are given by

$$\begin{aligned} P_{in} = \frac{1}{a+1}&[aEK(aE - e_{dc})^n \\ &- aEK(-E - e_{dc})^n] \end{aligned} \qquad (12)$$

and

$$P_0 = \frac{E_{dc}K}{a+1}[(aE - e_{dc})^n + a(-E - e_{dc})^n].$$

Then remembering that n is odd and substituting $E_{dc}/E=b$ the efficiency is found to be

$$\eta = \frac{b}{a}\left[\frac{(a-b)^n - a(1+b)^n}{(a-b)^n + (1+b)^n}\right] \times 100\%. \qquad (13)$$

Fig. 5 shows curves of η as a function of b for several values of a and n. Fig. 6 shows the maximum values of η obtainable by variation of b as a function of the exponent n. That is, Fig. 6 shows the variation of the maximum values of the curves of Fig. 5 as n is varied. From these two sets of curves it is noted that if either n or a is large, efficiencies of 20 per cent may reasonably be expected. Note also that for $n=5$ and $a=2$ the efficiency is 6.59 as compared with 5.1 per cent by the exact sine wave analysis.

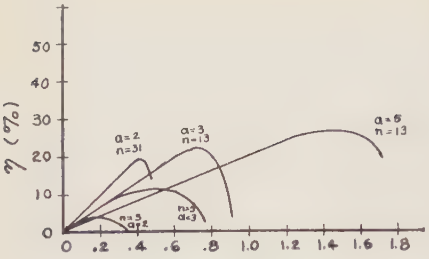

Fig. 5—Efficiency variation with changing *b*.

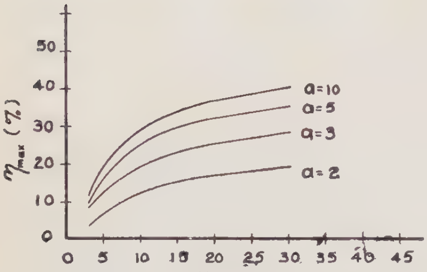

Fig. 6—Maximum efficiency for various exponents.

Although it is not likely that pseudo-rectification will replace rectification at low frequencies it does hold some interesting possibilities for application at high frequencies. With presently existing silicon carbide varistors one might expect to obtain of the order of 15 per cent efficiency of conversion of UHF power to dc in a bulk conversion process. This would essentially be unlimited in power capability because higher powers would only require larger amounts of bulk material.

The authors wish to thank K. E. Lytal for many helpful discussions.

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On the Modulation of Optical Masers*

Although there has been considerable discussion of Stark and Zeeman modulation of optical masers, most of the work thus far reported has been with Kerr cells, or ADP and KDP crystals external to the maser system. The purpose of this communication is to show what kind of results can be obtained by distorting the maser medium and the effective length of the resonate structure.

The equation for the frequency f of a maser oscillator for small frequency shifts from the line center may be written in the form[1]

$$(f - f_{mn}) = KQ_c/Q_l(f_c - f) \qquad (1)$$

where f_{mn} is the center frequency of the laser transition, f_c is the resonate frequency of the interferometer mode of interest, K is a constant near unity, Q_c is the Q of the interferometer mode and Q_l is the effective Q of the laser transition. A laser may be frequency modulated by changing either f_c or f_{mn}, and the corresponding changes in the output frequency are given by

$$\Delta f \approx (Q_l/Q_l + Q_c)\Delta f_{mn} \qquad (2)$$

and

$$\Delta f \approx (Q_c/Q_l + Q_c)\Delta f_c. \qquad (3)$$

The Q of the laser line is given by

$$Q_l = f_{mn}/\Delta f_{mn} \qquad (4)$$

where Δf_{mn} is the absorption line width. For the R_1 transition in ruby $Q_l \approx 10^3$.[2] The Q of the interferometer modes is given by[3]

$$Q_c = 2\pi l \epsilon^{1/2}/\lambda(1 - r) \qquad (5)$$

where l is the separation of the interferometer plates, ϵ is the relative dielectric constant of the maser material, λ is the wave length, and r is the reflection coefficient for the interferometer plates. Although this expression for Q_c is over simplified in that it neglects diffraction losses and losses in the maser material, it is adequate for our order of magnitude type calculations.

With $l = 1$ cm, $r = 0.9$, and $\epsilon = 1.76$ ruby, (5) gives $Q_c \approx 6 \times 10^6$. Thus (2) and (3) reduce to

$$\Delta f \approx 10^{-3}\Delta f_{mn} \qquad (6)$$

and

$$\Delta f \approx \Delta f_c \qquad (7)$$

From (6) it is apparent that the Stark and Zeeman effects must be very large if either of these effects are to be used for wide-band frequency modulation of a laser beam. For the R_1 transition in ruby the Stark coefficient is approximately given by 1.8×10^5 (cps cm/volt)[4] and thus a field of 10^5 volts/cm would give a frequency shift of only about 20 Mc. Similarly, Zeeman coefficient is approximately 2.6 Mc/gauss[5] and the corresponding laser frequency shift for 10 kilogauss is about 26 Mc.

A second method for using the Stark or Zeeman effect would be for amplitude modulation of an interferometer mode near the edge of the absorption line. However, for ruby with a field of 10^5 volts/cm we can shift an interferometer mode by only about 3 per cent of the natural line width and assuming a Gaussian line shape the maximum amount of amplitude modulation would be less than 3 per cent. In summary, both the Stark and Zeeman effects seem to be unattractive for modulating a ruby laser.

Another approach to the frequency modulation of a laser beam is to vary f_c. For a plane parallel plate interferometer

$$f_c \approx nv/l \qquad (8)$$

where n is the number of wavelengths between the interferometer plates and v is the velocity of light in the maser medium. To obtain frequency modulation of 10 kMc one must change either l or v by about two parts in 10^5. Unfortunately, getting mechanical motion with piezoelectric device of even an appreciable fraction of a wavelength of light appears to be difficult or impossible at these frequencies.

By modulating the dielectric constant of either a Kerr cell or a crystal of ADP which is placed between the maser medium and one reflector, the effective path length between the reflector plates may be varied by as much as half a wavelength.[6] Using the configuration shown in Fig. 1 both frequency and amplitude modulation may be obtained. These effects may be described by treating the maser system as a non-uniform transmission line. The effective reflection coefficient at surface one in Fig. 1 is given by $K_R = Z_R - Z_0/Z_R + Z_0$ where Z_0 is the characteristic impedance of the maser medium and Z_R is the effective load impedance at surface one. Z_R is given by the parallel combination Z_r, which is the effective shunt impedance of the boundary between the maser medium and the ADP crystal and Z_S which is the impedance of surface two as seen at surface one. In general Z_S is given by

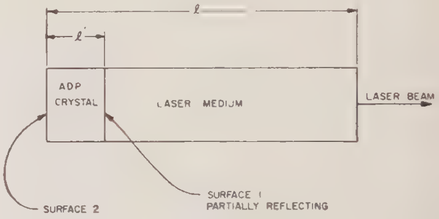

Fig. 1. A laser modulation system.

$$Z_S = Z_0' \frac{(Z_r' + Z_0')e^{\gamma l'} + (Z_r' - Z_0')e^{-\gamma l'}}{(Z_r' + Z_0')e^{\gamma l'} + (Z_r' - Z_0')e^{-\gamma l'}}$$

where l' is the thickness of the ADP crystal, γ is the propagation constant, z_0' is the characteristic impedance of ADP, and Z_r' is the impedance at surface two. If surface two is coated with a perfect reflector and we work with a linearly polarized beam, Z_S reduces to $Z_S = Z_0' \tanh \gamma l'$. Neglecting the losses in the ADP crystal, Z_S reduces to $Z_S = jZ_0' \tan \beta l'$ where $\beta = \omega\sqrt{\mu\epsilon'}$, μ is the permeability, ϵ' is the nonlinear dielectric constant,

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* Received May 2, 1962; revised manuscript received May 9, 1962

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and

$$Z_R = \frac{jZ_0'Z_r \tan \beta l'}{Z_r + jZ_0' \tan \beta l'}$$

By varying the voltage across the ADP crystal, we can vary tan $\beta l'$ from zero to infinity and K_R goes from minus one to $Z_r - Z_0/Z_r + Z_0$, which can be arbitrarily set with Z_r. One use for this modulation technique in addition to modulators for communications is for gating sharp high-power laser pulses.

Two problems which are expected to cause trouble with frequency modulated systems are the thermal changes in the dimensions of the system and the tracking of a single oscillator mode over a frequency region comparable with the separation between interferometer modes. The thermal coefficient of expansion for ruby is 8.7×10^{-6}. The frequency shift for a change in temperature is given by $\Delta f_c = f\alpha\Delta T \approx 3.7 \times 10^9$ cps/°C. The second of these problems can be minimized by using an interferometer with closely spaced plates.

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Control of Ruby Laser Oscillation by an Inhomogeneous Magnetic Field*

For many applications it is desirable to operate a pulsed laser in such a fashion that one or more short pulses of controlled amplitude, duration and timing are produced during or subsequent to a single pump lamp flash. Several methods have been reported which approach this goal: the "hair trigger" mode of pumping,[1] and "Q spoiling" in conjunction with normal pumping.[2–4] Another approach involves controlling the internal gain in the active material by the application of electric or magnetic fields. This note reports the demonstration of control of oscillation in a ruby laser by the application of an inhomogeneous magnetic field.

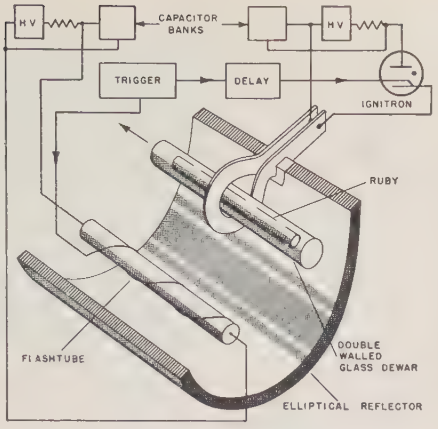

Fig. 1—Schematic diagram of experimental arrangement.

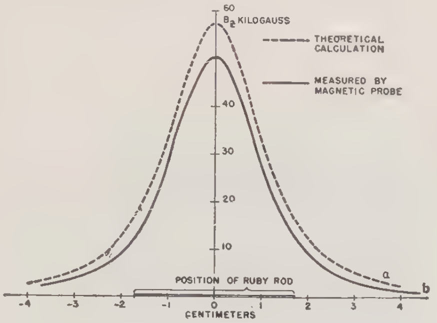

Fig. 2—Spatial dependence of axial magnetic field. (a) Calculation on the basis of current in circular loop. (b) Observed by magnetic probe coil.

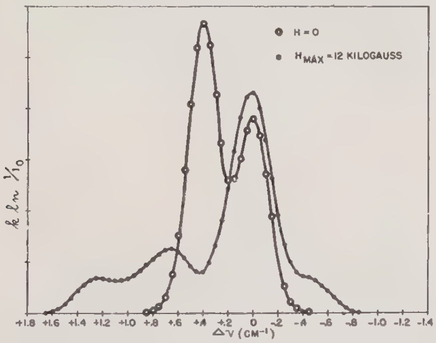

Fig. 3—Integrated extinction of ruby R_1 line calculated for single Cr isotope in configuration shown in Fig. 1. Linewidth chosen for $T=77°$K:0° oriented ruby:$H_{\parallel}C$.

The Zeeman splitting of the R_1 line of ruby has been thoroughly analyzed by Sugano, Tanabe and Tsujikawa[5] and clearly indicates the feasibility of utilizing Zeeman splitting for modulation of stimulated emission gain in optically pumped ruby. For optimum blocking of laser oscillation it is desirable that an inhomogeneous magnetic field be used to broaden the line rather than a homogeneous field which would maintain narrow linewidth in the shifted components.

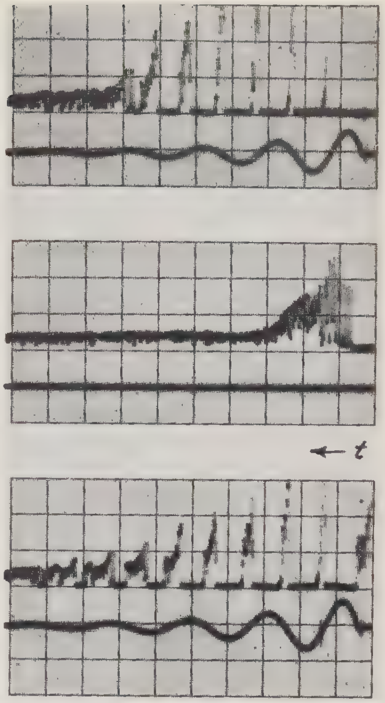

Fig. 4—Oscilloscope trace of portion of laser oscillation. Upper traces show photomultiplier output, lower traces show magnetic field intensity (100 kilogauss per division). Central exposure shows oscillation without application of magnetic field. Sweep speed: 10 μsec/cm; $T=77°$K.

A simple experiment to test these predictions was undertaken. A single loop of rectangular copper bar was placed around a 0° oriented sapphire clad ruby which was pumped by a Xenon flashtube in an elliptical reflector (Fig. 1). The magnetic field produced in the active material in this configuration is shown in Fig. 2. Calculation of the effective extinction coefficient for the entire rod in this configuration was carried out by numerical integration of the various Zeeman splittings over the active volume. A typical absorption spectrum computed in this way for the ruby at 77°K with a maximum field of 12 kilogauss at the center of the loop is shown in Fig. 3. The increase in threshold observed upon insertion of the loop implies that the part of the crystal shadowed by the loop does not become active, and this center section was therefore not included in the integration.

Experiments have been performed both at room temperature and at liquid nitrogen temperature. At room temperature the minimum field required at the center of the loop to prevent "spiking" was about 25 kilogauss. The line narrowing attendant upon cooling to 77°K makes the magnetic broadening much more effective, reducing the minimum required field at the center of the loop to about 6 kilogauss. Fig. 4 shows dual beam oscilloscope traces with laser oscillator output detected by a photomultiplier in the upper trace and magnetic field measured by probe in the lower trace, taken both with and without magnetic field under the same energy input to the flash lamp (about 1.4×threshold). The crystal was in liquid nitrogen during these exposures. The increase in amplitude of the pulses over the unmodulated case is evident. The origin of this effect in a "supersaturation" of population inversion has been pointed out by Hellwarth.[2] It should be noted that with the present method of modulation the active volume is effectively broken up into many smaller noninteracting volumes, which minimizes the enhancement of spontaneous emission by stimulated emission during the pumping as long as the magnetic field is on.

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* Received April 26, 1962.

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The Zeeman splitting indicates an appreciably greater sensitivity of 90° oriented ruby to magnetic field modulation, but we have not yet been able to test this conclusion experimentally. Work is in progress on improved configurations, a primary aim of which is to avoid reduction of the incident pump light by the copper loop. Studies of frequency- shifting of laser pulses due to the residual magnetic field at onset of oscillation are also in progress.

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Current Gain in Metal-Interface Amplifiers*

Schwarz and Spratt,[1] in a letter submitted to these Proceedings on February 21, 1962, describe a device which makes use of three thin films deposited upon a Ge single-crystal substrate and point out that a similar current transfer mechanism may occur in the metal-interface amplifier.[2–4] In a full paper submitted to *Solid-State Electronics* on February 7, 1962, the undersigned have described[5] an extensive series of measurements upon metal-interface amplifier structures, arriving at the conclusion that a similar mechanism is responsible for most, if not all, of the current transferred. The controversy concerning the active mechanism of the

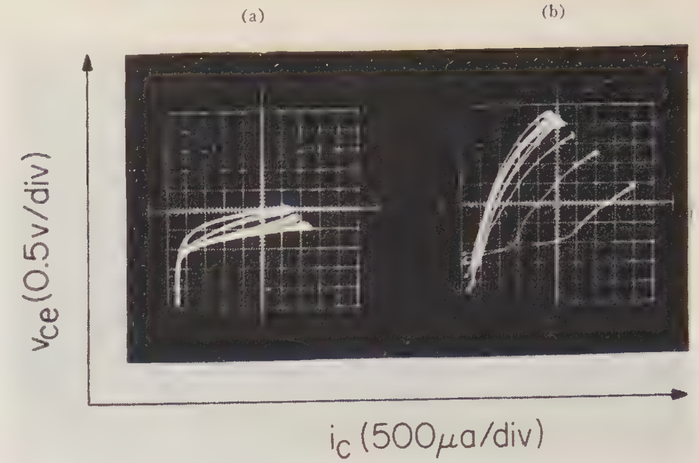

Fig. 1—(a) Grounded-emitter collector characteristics with current input, 5μa/step. (b) Same characteristics with voltage input 0.2 v/step

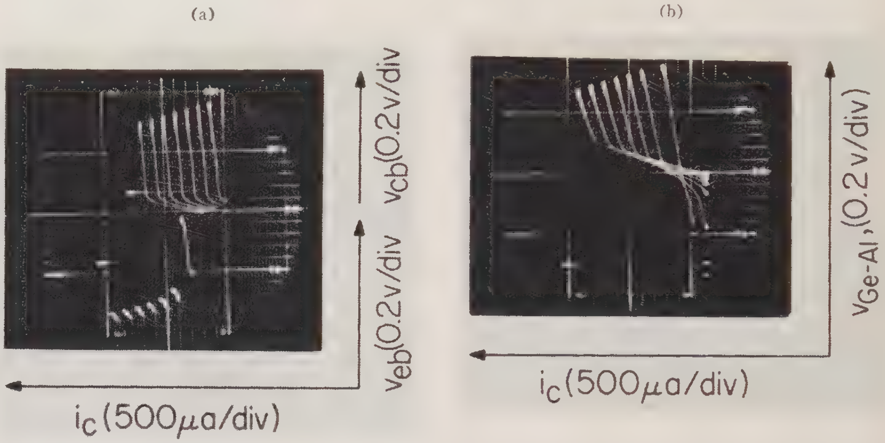

Fig. 2 (a) Grounded-Al collector and transfer characteristics with normal Au polarity (negative). (b) Grounded-Al collector characteristics with Au (emitter) polarity reversed (positive).

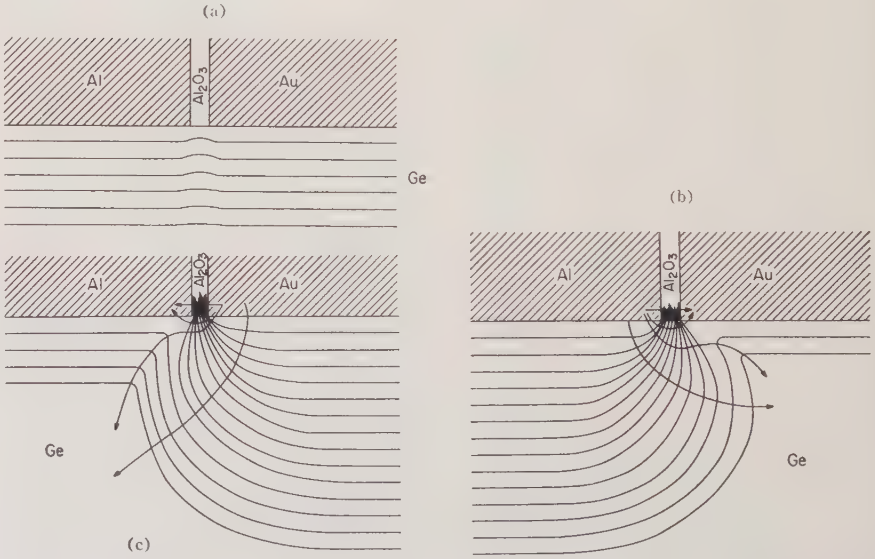

Fig. 3—(a) Potential distribution in the interaction region of the Ge, no bias, uniform potential assumed. (b) Potential distribution in the interaction region of the Ge, normal bias, Au negative with respect to Al. (Arrows show possible electron paths.) (c) Potential distribution in the interaction region of the Ge. Au positive with respect to Al. (Arrows show possible electron paths).

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MIA stems from comments by Hall[6] concerning the unlikelihood of hot-electron mean-free paths of the order of 1000 Å in thin films of Al, as was earlier proposed by Spratt, Schwarz and Kane.[2] Hall further pointed out that thin films, particularly of the order of 100 Å thick, commonly contain pinholes, thus providing an alternative current transfer mechanism by means of injection directly into the space-charge region at the surface of the Ge.

It is quite trivial to show that in conventionally fabricated MIA structures the Au is in direct contact with the Ge. Since under *n-p-n* bias the Au-Ge diode may act as reverse-biased diode shunting the active structure, this only suggests the possibility of injection directly into the space-charge region. It remains for three other measurements to demonstrate conclusively that the important current transfer mechanism is by injection into the space-charge region. Fig. 1(a) shows the grounded-emitter collector characteristics of a metal-interface amplifier biased as an *n-p-n* transistor with a current source input to the Al base. Fig. 1(b) shows the same device driven with a voltage source. If the MIA were a hot-electron tunnel-emission device, this difference in the characteristics would not be expected. On the other hand this behavior is understandable in a device employing injection into a space-charge region. Second, if the MIA were a hot-electron device, reversing the polarity of the emitter would result in no current transfer. Fig. 2(b) shows the collector characteristics observed when the input polarity is reversed. These characteristics were obtained by grounding the Al base and applying a positive potential to the Au emitter, and are readily identified as grounded-emitter collector characteristics. Fig. 2(a) shows conventional grounded-base collector characteristics of the same device with normal (negative) bias applied to the Au emitter. From the latter measurements a model shown in Fig. 3 was established. This potential configuration readily explains the several observations made on this device, namely,

1) Reversal of input polarity causing the Al base to inject electrons into the space-charge region thus yielding grounded-emitter characteristics when the Al is grounded,
2) Au-Al_2O_3-Al *I-V* characteristics which do not resemble tunneling characteristics,
3) Current flow between the Au and the Al when nontunneling thickness of oxide and deliberately introduced pinholes are present,
4) Similarity of electrical characteristics when pinholes are deliberately introduced, or two overlapping Au, Al_2O_3-Al structures are deposited on Ge.

Conceptually, our model differs from that of Schwarz and Spratt in that space-charge limited injection occurs from the metal into the space-charge region of the Ge. As is well known,[7–9] a metal may inject either electrons or holes into the space-charge region of a semiconductor depending upon whether it is biased negatively or positively with respect to the space-charge potential. In the present model, the base metal clamps the space-charge potential (in the vicinity of the Al_2O_3) more effectively than was heretofore possible with other geometries,[10] and allows the other metal nearby to inject. This clamping action also prevents the deleterious feedback which prevented power gain in the depletion-layer transistor.[11]

The third measurement involves the fabrication of *p-n-p* structures using the same techniques on *p*-type Si. On such structures grounded-emitter and grounded-base collector characteristics have been observed as well as current transfer with reversal of input polarity. In this latter structure, tunnel-emission from the emitter cannot contribute to the collector current. These investigations strongly suggest the correctness of Hall's proposal that the dominant current transfer mechanism is via injection directly into the space-charge region.

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Germanium and Silicon High-Frequency Esaki Diodes*

Fundamental oscillations at frequencies extending well into the millimeter-wave region have been observed in waveguide-mounted, formed-point-contact Esaki diodes of several III–V semiconducting compounds, and the fabrication of these diodes has been described.[1] This communication briefly describes the fabrication of germanium Esaki diodes[2] which have been observed to oscillate into the 4–5 millimeter-wave region and silicon Esaki diodes which have provided oscillation into the 6–7 millimeter-wave region.

To obtain the highest possible oscillation frequencies in the available waveguide circuits[1] it was necessary to produce low peak current diodes with maximum peak current densities. This combination so far has been achieved most readily by the use of very heavily doped semiconductors in conjunction with point-contact diode geometry. Consequently, the most heavily doped semiconductors from which low i_p units could be made consistently by present point forming or welding techniques, without subsequent etching, were employed. The selected *n*-type germanium[3] contained $8–9 \times 10^{19}$ arsenic atoms/cc ($\rho = 0.00051$ ohm-cm) and the *p*-type germanium had 1×10^{20} gallium atoms/cc ($\rho = 0.00056$ ohm-cm). The *p*-type silicon was doped with boron to a resistivity of 0.0003–0.0004 ohm-cm ($N_a = 3–4 \times 10^{20}$/cc), and the *n*-type silicon contained 6–8 $\times 10^{20}$ phosphorus atoms/cc ($\rho = 0.0003$–0.0004 ohm-cm).

Gallium, plated onto pointed wires of other materials,[4] served as an acceptor source for the formation of junctions on *n*-type germanium, and several weight per cent antimony or arsenic carried in lead or tin served as the point donor source for use with *p*-type germanium. Arsenic in lead was employed with *p*-type silicon, and boron in aluminum with the *n*-type silicon. In all cases the junctions were formed by the application of a short, low voltage pulse to a mechanically light but electrically stable contact between a suitable point and the etched (CP-8) semiconductor surface.[5] The pulse generator had an impedance of a few ohms.

I–V characteristics of diodes of these types are illustrated in Fig. 1. The relatively high values of peak voltage shown, especially for the germanium units, are typical of diodes fabricated from the very heavily doped semiconductors. Microscopic examination of semiconductor surfaces from which formed point contacts had been removed indicated that the peak current densities of both types of 1–5 ma germanium diodes tended to range from 50,000 a/cm² to 90,000 a/cm², and sometimes exceeded 100,000 a/cm². The surface disturbances caused by the formation of lower peak current units were difficult to locate unambiguously.

In waveguide circuits[1] measuring 0.010 ×0.148 or 0.010×0.122 inches in cross section, fundamental oscillations to frequencies above 65 Gc were obtained from diodes of both *n*- and *p*-type germanium. The highest observed frequency, 67.2 Gc, was achieved with a unit of *n*-type material. Also, the average oscillation frequency for a number

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* Received May 16, 1962.

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[4] C. A. Burrus, "High frequency silicon varactor diodes," *J. Appl. Phys.*, vol. 32, pp. 1166–1167; June, 1961.

[5] (111) crystal plane.

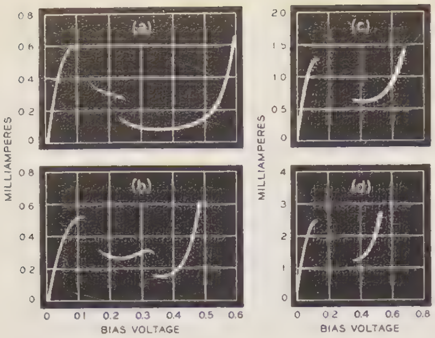

Fig. 1—60 cps I-V characteristics of typical formed-point-contact high-frequency Esaki diodes. a) Germanium, $N_a = 1 \times 10^{20}$ Ga/cc, Pb-Sb point; b) Germanium $N_d = 8\text{–}9 \times 10^{19}$ As/cc, Ga point; c) Silicon, $N_a = 3\text{–}4 \times 10^{20}$ B/cc, Pb-As point; d) Silicon $N_d = 6\text{–}8 \times 10^{20}$ As/cc, Al-B point. The diodes in a) and b) are oscillating, those in c) and d) are switching.

of diodes of n-type germanium was slightly higher than the average for nominally similar diodes of the p-type semiconductor. All units had peak currents of 0.2–0.8 ma and were constructed directly in the waveguide. It is inferred that, with these junction forming techniques, the combination of gallium point contacts and n-type germanium has yielded the highest peak current densities.

Diodes also have been fabricated in the same way using aluminum points with n-type germanium. Oscillation above 50 Gc seldom was observed with these units, however, and their maximum peak current densities, as indicated by the apparent junction areas, did not equal those exhibited by either of the other diodes.

Oscillation at frequencies to 48 Gc has been detected in diodes of p-type silicon built into the same 0.010×0.148-inch waveguide circuit, but units for use at such frequencies have not been produced consistently. In general, the apparent peak current densities of these diodes has been relatively low and the i_p/i_v ratios have been poor.

Attempts to fabricate Esaki diodes for high-frequency operation from n-type silicon have rarely resulted in diodes with suitable dc characteristics, and high-frequency tests have not been undertaken. The difficulty is believed due, not to inadequate donor concentrations in the semiconductor, but to insufficient acceptor atoms available from the point alloy. Previously, where it has been necessary to use an alloy as the point material in diodes of this type, consistent results generally have been obtained only if this alloy contained at least 10–15 atomic per cent of the dopant in reasonably uniform distribution throughout the carrier. A suitable alloy containing the requisite amount of boron, the only acceptor useful in silicon for this application, has not been available.

The author is indebted to R. F. Trambarulo for information concerning his prior work on formed-point-contact germanium Esaki diodes, to F. A. Trumbore for several samples of germanium, and to Mrs. E. T. Handleman for a sample of silicon.

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Side Emission from Ruby Laser Rods*

The population of the upper laser energy level and hence the spontaneous emission should, according to the theory of optical masers,[1] remain constant during oscillation. Measurements[1] on CaF_2:Sm^{++} of the emission from the side of the laser rod showed however that this was not the case, but that the emission varied as the lamp intensity. It was therefore suggested that most of the emitting Sm^{++} did not participate in laser action. We have carried out similar experiment with cylindrical ruby laser rods.

The intensity of the R_1 (lasing) or R_2 line was measured from the side with a monochromator and photomultiplier. The intensity of the end emission was measured simultaneously with a solar cell. Fig. 1 shows the R_1 side emission from a silvered ruby rod having polished sides. The rate of emission suddenly increases at the start of laser action, and the emission continues to rise during oscillation. This rise can partly be attributed to scattered laser light. However, the emission remains large even after laser action has ceased. This behavior is attributed to amplified spontaneous emission or superradiance, enhanced by the long path lengths resulting from total internal reflection from the side of the rod. The direction of propagation may be confined to planes perpendicular to the rod axis, as suggested by Schawlow in the work of Weider and Sarles,[2] or may follow spiral paths back and forth along the rod.

Fig. 2 shows the R_1 side emission when laser action was suppressed by removing the silver from both ends of the rod. Superradiance was observed in the absence of laser action. Thus the steep rise in the side emission was not a direct result of the laser pulse.

The superradiant effects described above were absent in a ruby rod with a rough-ground side. Under lasing conditions, the R_1 side emission followed the laser pulse and was assumed to consist of scattered laser light. The intensity just before and just after the laser pulse was the same, however, and in accordance with theory. The R_1 side emission from an unsilvered rough-sided rod, in contrast to Fig. 2, showed only a smooth rise and decay.

Because of the superradiance and scattered light it was not possible to verify the theory by observation of the R_1 emission. The R_2 emission was therefore investigated, since because of the small relaxation time[3] between the R levels ($<10^{-7}$ sec) the population of the R_2 level should be directly related to that of R_1 during oscillation. It was found that the intensity of the R_2 side emission rose continuously during laser action, both for silvered and unsilvered ends and for smooth and rough sides. It might be assumed that this occurred because an appreciable fraction of the crystal was not lasing. However, it was also observed that after the start of laser action the R_2 side emission rose only about half as much as the R_2 end emission. Therefore it appears that at least part of the continued increase in R_2 emission results from a long self-absorption time constant.

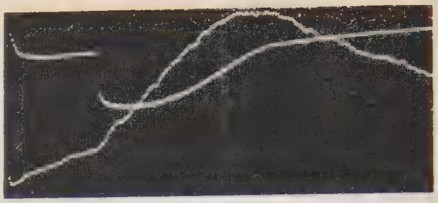

Fig. 1—Ruby rod with polished sides, silvered with 10 per cent transmission. Laser emission from end (top trace) and simultaneous R_1 emission from side (bottom trace). The laser pulse starts at 400 μsec and ends at 1200 μsec. 200 μsec/division.

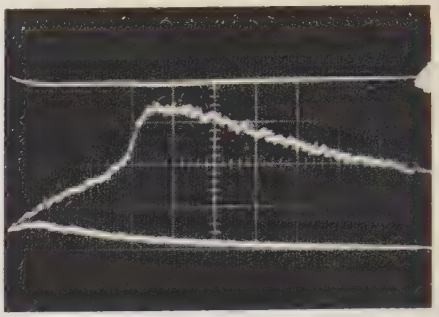

Fig. 2—Ruby rod with polished sides but no silvering. Emission from end (top trace) and simultaneous R_1 emission from side (center trace). 200 μsec/division. The flash-lamp intensity is shown in the bottom trace.

The reduction of spurious modes in optical amplifiers and oscillators is important for optimum operation. If long path lengths (other than in the required direction of amplification) are present in an optical amplifier, excessive pump power will be required to obtain a given inversion. Also, depending on the coupling mechanism present, excessive noise may be generated. The superradiance reported here for cylinders can be reduced by roughening the sides, although this has the disadvantage of reducing the amount of pumping light entering the crystal because of scattering. A better method of reducing the number of total internal reflection paths would be to coat the rod with a clear sheath of material optically matched to the active crystal. This also has the advantage of focussing the pumping light.[4]

Acknowledgment

The authors wish to acknowledge the skillful fabrication of the laser rods by J. N. Cairns, and the technical assistance of E. L. Dimock, J. A. Marier and B. A. Kettles.

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* Received April 23, 1962; revised manuscript received May 7, 1962.

[1] W. Kaiser, C. G. B. Garrett and D. L. Wood, "Fluorescence and optical maser effects in CaF_2:Sm^{++}," *Phys. Rev.*, vol. 123, pp. 766–776; August, 1961.

[2] I. Weider and L. R. Sarles, "Advances in Quantum Electronics," J. R. Singer, Ed., Columbia University Press, New York, N. Y.; 1961.

[3] A. Kiel, "Advances in Quantum Electronics," J. R. Singer, Ed., Columbia University Press, New York, N. Y.; 1961.

[4] G. E. Devlin, *et al.*, "Composite rod optical masers," *Applied Optics*, vol. 1, pp. 11–15; January, 1962.

Maser Operation at 96 kMc with Pump at 65 kMc*

Maser operation has been demonstrated at a frequency of 96.3 kMc using a pump frequency of 65.2 kMc. The material used for the maser was the iron ion, Fe^{3+} in a host of TiO_2 rutile. The high dielectric constant and low-loss tangent of the rutile allowed the sample itself to be used as a resonant cavity. The sample size was approximately 4×10^{-4} cubic inches and the Fe/Ti ratio was approximately 10^{-3}.

The spin Hamiltonian[1] in the form of a secular determinant has been programmed into the IBM 7090 computer at Westinghouse and solved as a function of the two angles of orientation (θ, ϕ) and the applied magnetic field, where θ is the angle the magnetic field makes with the [110] crystal axis and ϕ is the angle between the projection of the magnetic field on the (110) plane and the $[\bar{1}10]$ crystal axis.

With the solutions obtained by the computer, it was possible to arrange the energy levels as shown in Fig. 1. The configuration allows pumping three transitions simultaneously, *i.e.*, $f_{13} = f_{42} = f_{53} = f_{\text{pump}}$. If the relaxation rates are nearly equal and if $2f_{12} > f_{13}$, then levels 5–4, 3–2 and 5–2 will be inverted and stimulated emission can take place at either f_{54}, f_{32} or f_{52}. Since in this experiment it was desired to have the signal frequency equal to f_{52}, it is necessary to suppress oscillations at f_{54} and f_{32}. This was accomplished simply by making certain that there were no high Q resonant cavities at the frequency f_{54} or f_{32}.

To the author's best knowledge, this is the first time that maser operation has been demonstrated with a pump frequency so much lower than the signal frequency.

Maser oscillations were detected by the use of a 30 Mc IF superheterodyne system with a swept local oscillator covering 250 Mc centered at 96.3 kMc. The detected output of the IF amplifier is shown in Fig. 2 with both sidebands visible in the photograph. The maser could also be made to oscillate simultaneously at two frequencies separated by about 150 Mc. Investigation disclosed that there were two high Q cavities in the rutile which were separated by about 150 Mc; thus, it appears that the oscillations were occurring at these cavities.

The upper trace of Fig. 3 shows the signal power reflected from the crystal and microwave assembly with the pump power on and the crystal positioned so that it is on a paramagnetic resonance at both the signal and pump frequencies. The center trace shows the same conditions except that the pump power has been turned off to show the absorption at the signal frequency due to the paramagnetic resonance. The bottom trace shows the microwave cavities in the rutile when there is no paramagnetic absorption.

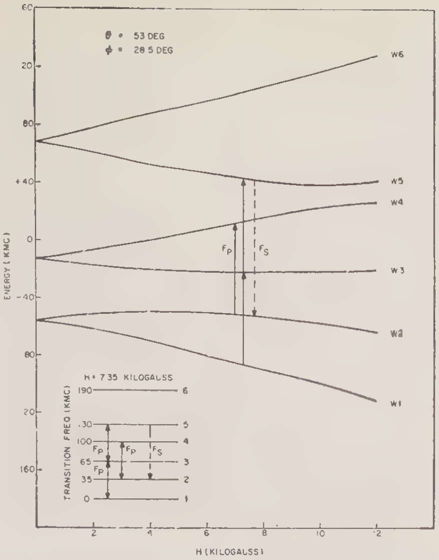

Fig. 1—Energy levels of Fe^{3+} in TiO_2 as a function of magnetic field at $\theta = 53$ and $\phi = 28.5$.

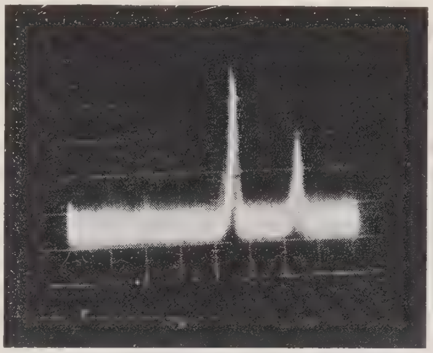

Fig. 2—Maser oscillations at 96.3 kMc with pump at 65.2 kMc: $H = 7.35$ kilogauss, $T = 2.1°$ K, $\theta = 53$ and $\phi = 28.5$.

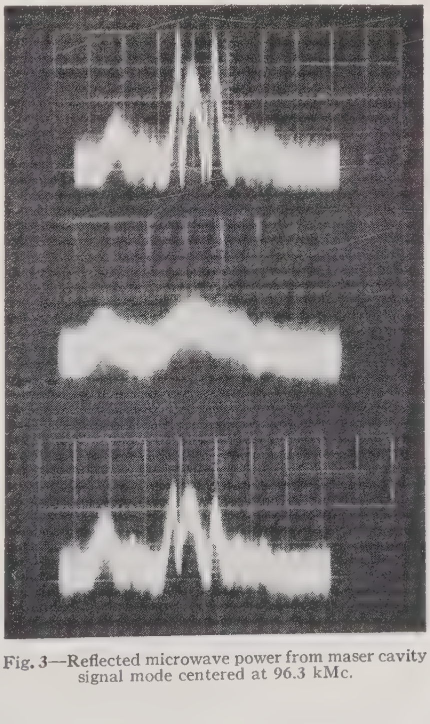

Fig. 3—Reflected microwave power from maser cavity signal mode centered at 96.3 kMc.

From Fig. 3 it can be seen that in order to obtain maximum gain at any one frequency, it will be necessary to reduce the number of resonant cavities and to maximize the coupling to only one cavity. This will be done and a measure of the gain bandwidth product will be made.

ACKNOWLEDGMENT

The author is grateful to all the persons who have helped make this project successful; in particular, I would like to thank T. W. Hollis for his helpful suggestions and J. Hamburger and O. L. Bishop for their help in making the many necessary measurements.

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* Received May 16, 1962. This work was supported by the Department of the Air Force, ETL, Aeronautical Systems Division, Dayton, Ohio.

[1] D. L. Carter and A. Okaya, "Electron Paramagnetic Resonance of Fe^{3+} in TiO_2 (Rutile)," Department of Physics, Columbia University, New York, N. Y., September, 1959.

Continuous Operation of the $CaF_2:Dy^{+2}$ Optical Maser*

Stimulated emission in $CaF_2:Dy^{+2}$ was recently announced by Kiss and Duncan,[1] and a paper has been submitted for publication. This letter reports lifetime and spectroscopic data on divalent dysprosium in CaF_2, and continuous operation of the $CaF_2:Dy^{+2}$ optical maser at 20°K.

In this work dysprosium in the divalent state is produced by irradiating a crystal of $CaF_2:Dy^{+3}$ with γ rays. γ irradiation converts a crystal of $CaF_2:Dy^{+3}$ from nearly transparent to a light brown color. The absorption spectrum associated with the divalent dysprosium produced consists of a strong band extending from 2300 to 4900 Å and three weaker bands ~800 Å wide at 5800, 7200, and 9100 Å. Pumping into any of these bands produces strong infrared fluorescence in the region 2.3–2.6 microns. The emission at 77° K consists primarily of six sharp lines, each about 0.5 cm^{-1} wide (Fig. 1). At 20°K, essentially only the two strongest lines are observed, at 2.360 and 2.344 microns. Under pulse illumination conditions, maser action is observed only in the strongest line at 2.36 microns at both 77° and 20°K. Near threshold in pulse operation the crystal integrates the light flux for at least 0.7 msec before the onset of stimulated emission, providing an estimate ~1 msec for the fluorescence lifetime.

Continuous operation experiments were

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* Received May 10, 1962; revised manuscript received May 15, 1962.

[1] Z. J. Kiss and R. C. Duncan, American Physical Society Meeting; April, 1962. (Post deadline paper.)

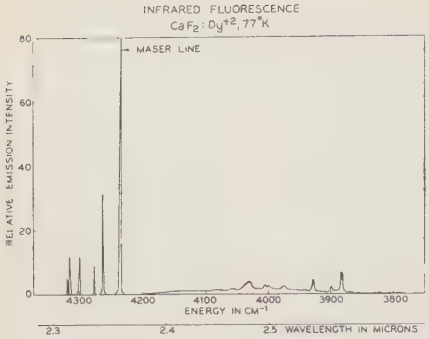

Fig. 1—Infrared fluorescence in $CaF_2:Dy^{+2}$ at 77°K. Maser action is observed in the line at 2.36 microns.

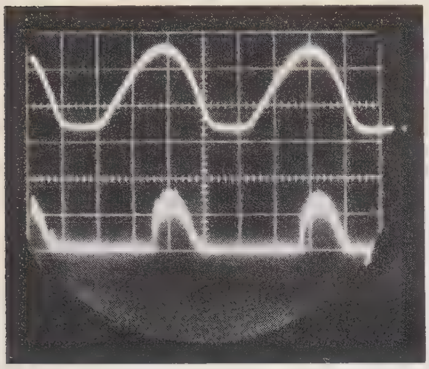

Fig. 2—Semicontinuous maser action in $CaF_2:Dy^{+2}$ at 20°K. Pumping is provided by an AH6 mercury lamp driven by 60-cps alternating current (upper trace). Stimulated emission is shown in the lower trace. The time scale is 2 msec/division and the power input to the lamp is 800 w, 25 per cent above threshold.

conducted in an elliptical pumping configuration similar to that used previously for $CaWO_4:Nd^{+3}$.[2] The crystal is cooled by inserting it into a small quartz Dewar containing liquid hydrogen or nitrogen. The radiation transmitted through the lightly silvered end of the crystal (~1 per cent transmitting) is monitored by a gold-doped germanium detector cooled to 77°K.[3] A germanium window in front of the detector eliminates unwanted radiation below 1.6 microns.

There are two operational differences between the experiment described here and that reported for $CaWO_4:Nd^{+3}$. First, a dynamic cooling system is not employed. The crystal is simply immersed in a reservoir of liquid hydrogen contained in a quartz Dewar. At no time did the pump power level required for continuous operation cause the crystal to become encased in a gas jacket and lose thermal contact with the bath. Second, a filter to eliminate harmful or unwanted bands of pump radiation, as was required for $CaWO_4:Nd^{+3}$, is not necessary for $CaF_2:Dy^{+2}$. Radiation below 4000 Å, which will prevent continuous operation of $CaWO_4:Nd^{+3}$, is useful pump energy for $CaF_2:Dy^{+2}$, although the dominant pump bands lie beyond 5000 Å.

In the following the AH6 mercury lamp is powered by 60-cps alternating current, producing pump light at 120 cps. The threshold for continuous operation of the $CaF_2:Dy^{+2}$ crystal used is quite low at 20°K (650-w rms input power to the lamp) and continuous operation is easily obtained with either ac or dc power into the lamp. Operation of the lamp on dc reveals less information, however, and only the experiment demonstrating maser action in the semicontinuous mode will be described. An oscilloscope trace of stimulated emission in semicontinuous operation at 20°K is shown in Fig. 2. The upper trace shows the time variation of pump light intensity on a time scale of 2 msec/division. The intensity varies from a maximum to a nearly zero level of illumination. The rms power input to the lamp is 800 w, 25 per cent above threshold for semicontinuous operation. Maser output is displayed in the lower trace, triggered simultaneously with the lamp trace. On each cycle the maser crystal absorbs pump light until the critical inverted population density is achieved between the two states involved in the maser transition. An abrupt burst of stimulated emission then appears, continuing until the pump power falls below the critical level. Examination of the maser output trace reveals a marked asymmetry in the pattern. On each cycle maser oscillation begins at a point nearly coinciding with the peak intensity of illumination from the lamp. Yet oscillation continues until the intensity of illumination is down to some 45 per cent of peak value, a consequence of the long fluorescence lifetime in $CaF_2:Dy^{+2}$. The pattern is consistent with a lifetime ~1 msec. The duration of continuous operation is limited only by the hydrogen capacity of the Dewar.

A second crystal examined was observed to oscillate continuously at a power input to the lamp of <350 w at 20°K. At 20°K, the peak output power transmitted through the 1 per cent transmitting end reflector is about 0.6 mw at 1.8 × threshold and 2.5 mw at 3 × threshold. Low dysprosium concentration and incomplete conversion to the divalent form are important factors limiting power output.

Acknowledgment

The author would like to thank R. A. Thomas for his assistance throughout all phases of this work, and Dr. G. D. Boyd, who pointed out to the author the γ-irradiation method for producing divalent thulium in CaF_2, and whose investigation of the infrared transmission of silver films made possible a considerable improvement in power output. He wishes to express his appreciation to H. Guggenheim for carrying out the γ-irradiation, and whose experience in this technique was most helpful. He also wishes to thank Miss D. M. Dodd for absorption data, P. M. Ness for preparing the maser crystal, and A. E. DiGiovanni for technical assistance. Dr. C. G. B. Garrett contributed several useful comments on the manuscript. The crystal was obtained through the courtesy of W. Hargreaves of the Optovac Company.

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[2] L. F. Johnson, G. D. Boyd, K. Nassau, and R. R. Soden, "Continuous operation of the $CaWO_4:Nd^{+3}$ optical maser," Proc. IRE (*Correspondence*), vol. 50, p. 213; February, 1962.

[3] The author is indebted to Prof. H. Levinstein of Syracuse University, N. Y., for providing the crystal used to make the detector.

WWV and WWVH Standard Frequency and Time Transmissions*

The frequencies of the National Bureau of Standards radio stations WWV and WWVH are kept in agreement with respect to each other and have been maintained as constant as possible with respect to an improved United States Frequency Standard (USFS) since December 1, 1957.[1] The corrections reported here were arrived at by means of improved measurement methods based on NBS LF and VLF transmissions. The values given are 5-day running averages of the daily 24-hour values for the period beginning at 1800 UT of each day listed.

The WWV and WWVH time signals are also kept in agreement with each other. Since they are locked to the frequency of the transmissions, a continuous departure from UT2 may occur. Corrections are determined and published by the U. S. Naval Observatory. The broadcast signals are maintained in close agreement with UT2 by properly offsetting the broadcast frequency from the USFS at the beginning of each year when necessary. This new system was commenced on January 1, 1960.

Subsequent changes were as follows:

Frequency Offset, with reference to the USFS

January 1, 1960	−150 parts in 10^{10}
January 1, 1962	−130 parts in 10^{10}

Time Adjustments, with reference to the Time Scale UT2

December 16, 1959	retardation, 20 msec
January 1, 1961	retardation, 5 msec
August 1, 1961	advancement, 50 msec

Adjustments were made at 0000 UT on the foregoing dates; an advancement means that the signals were adjusted to occur at an earlier time than before.

WWV Frequency
With Respect to U. S. Frequency Standard

1962	Parts in 10^{10}†
April 1	−129.7
2	−129.7
3	−129.5
4	−129.5
5	−129.5
6‡	−129.5
7	−130.5
8	−130.6
9	−130.7
10	−130.7
11	−130.8
12	−130.8
13	−130.9
14	−130.9
15	−130.9
16	−130.9
17‡	−130.8
18	−130.4
19	−130.4
20	−130.4
21	−130.4
22	−130.5
23	−130.4
24	−130.4
25	−130.3
26	−130.2
27	−130.2
28	−130.2
29	−130.1
30	−130.1

† A minus sign indicates that the broadcast frequency was below nominal. The uncertainty associated with these values is $\pm 5 \times 10^{-11}$.

‡ WWV frequency was adjusted as follows at 1900 UT: April 6, -0.9×10^{-10}; April 17, $+0.5 \times 10^{-10}$.

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* Received May 25, 1962.

[1] "National standards of time and frequency in the United States," Proc. IRE (*Correspondence*), vol. 48, pp. 105–106; January, 1960.

Measurement of Laser Output by Light Pressure*

The use of the laser oscillator in physical experiments requires the measurement of the output radiation. In such measurements, as they are currently made by the authors and other researchers,[1] a blackened cone serves as a simulated blackbody absorber. Absorption of the energy of the laser pulse causes a temperaure rise which can be measured by a platinum resistance, thermocouple, or thermistor. If the mass and specific heat of the cone are known, the absorbed energy can be calculated.

This method has proven highly successful for energies from a few hundredths of a joule to perhaps five joules. But for higher energy pulses the accuracy and consistency fall rapidly because of incomplete absorption and deterioration of the absorbing material. It therefore becomes necessary to absorb externally, or else to deflect an accurately known portion of the high energy pulses. Future developments should yield greatly increased energy outputs, which will eventually make this method of measurement impractical.

It is the purpose of this note to demonstrate that a practical system can be constructed to measure the pressure of a laser pulse on a reflecting surface, and hence the total energy of the pulse. By proper selection of coatings, such a surface can be made very highly reflecting, and thus suffer no significant deterioration. If appropriate system characteristics are chosen, there appears to be no practical limitation on the maximum measurable pulse energy.

It should be noted that though the present discussion treats only pulsed output, the method applies equally well to lasers producing CW output. It appears, however, that these will remain, at least for the present, in the range handled more conveniently by absorption measurements.

Radiation pressure can be conveniently measured by a torsional pendulum (Fig. 1). For such a system, the deflection in radians per joule reflected is easily calculated. Since energy per photon $=h\nu=Mc^2$, and momentum per photon $=Mc=h\nu/c$, the total momentum change per photon $=2h\nu/c$, assuming normal incidence and perfect reflection. The total momentum change per pulse is therefore given by $2h\nu N/c=F\Delta t$, where N is the total number of photons per pulse, F the force exerted on the reflecting surface, and Δt the duration of the pulse. If the period of free oscillation of the torsional system $\tau \gg \Delta t$, then at $\theta=0$, $\omega=(2l/cI)h\nu N$. For energy considerations, $\frac{1}{2}K\theta^2=\frac{1}{2}I\omega^2$, from which

$$\theta = (2l/c\sqrt{IK})E \qquad (1)$$

where E is the pulse energy, K the torsional stiffness, and I the system's moment of inertia.

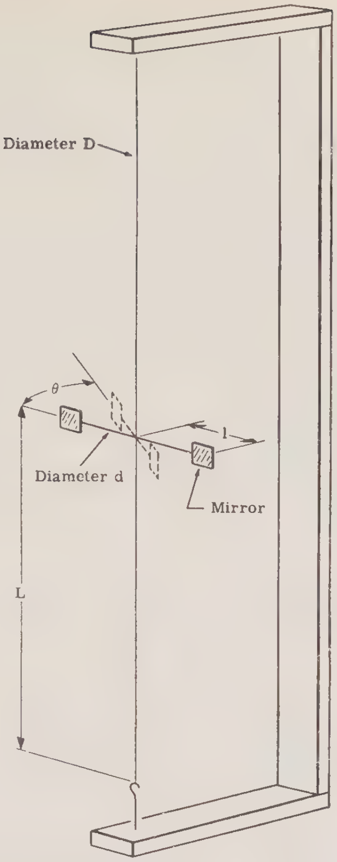

Fig. 1—Torsional pendulum for measurement of light pressure.

Dynamic calibration is accomplished by changing the moment of inertia and noting the resulting change in period of free oscillations.

The system must be operated in a vacuum in order to reduce the "radiometer" effect due to heating of the air molecules and reflector. The mean free path of the air molecules should be at least on the order of the dimensions of the system, *i.e.*, centimeters. An order of magnitude calculation indicates that $\lambda \sim 10^2$ cm for air at 10^{-4} mm Hg. Thus a pressure of 10^{-4} mm Hg or less should make any heating effects negligible. To evaluate this method qualitatively, we have constructed such a torsional system; it is shown in Fig. 2. The primary concern was to make the system sensitive enough for measurements in the range of the blackened cone. For this purpose, we have chosen a quartz torsional fiber approximately 32 μ in diameter and 48 cm long ($L=24$ cm, see Fig. 1). The cross arm, a second quartz fiber 250 μ in diameter and 8.5 cm long ($l=4.25$ cm), supports two silvered mica mirrors weighing 25.5 mg. There is an additional centrally mounted, silvered-cover glass to allow a read-out light beam introducing negligible torque into the system. These values result in an expected deflection of approximately 5.7×10^{-3} radians per joule. The actual sensitivity, taken from period measurements, was found to be 5.2×10^{-3} radians per joule.

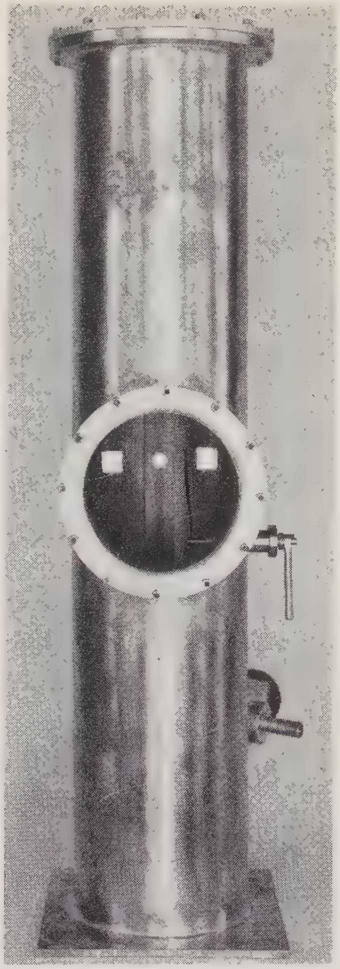

Fig. 2—Experimental system for measurement of laser energy.

In a test of the device, a deflection of 13.9×10^{-3} radians was observed. After allowance for reflections at the glass and mirror surfaces, this indicates a total pulse energy of 3.28 joules. The blackbody absorber measured the same sample under the same conditions of input joules and sample temperature at 3.25 joules.

A more sensitive device, using a beam splitter to divert a known amount of each pulse into the blackbody absorber is being designed. We plan to use eddy current damping since in testing the present system we have experienced difficulty in damping oscillations between pulses.

In summary, it appears that though this method is impractical with low energy pulses and current CW lasers, it does offer an attractive means of handling the extremely high energies which are certain to be produced by future lasers.

The authors wish to express their appreciation to Profs. S. K. Clark and C. W. Peters for valuable discussions and suggestions. The excellent technical assistance of F. Alred and M. Smith is gratefully acknowledged.

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[1] S. Koozekanani, P. P. Debye, A. Krutchkoff, and M. Ciftan, "Measurements of the laser output," Proc. IRE (*Correspondence*), vol. 50, p. 207; February, 1962.

The Effect of an Ether Drift on the Oscillation Frequency of a Beam-Type Maser*

Several years ago, in the course of analyzing the interpretation of the results of the Cedarholm, Bland, Havens, and Townes (CBHT)[1] ether drift experiment, we studied an explicit theory of the effect under investigation based upon a theory of the maser cavity modes in the presence of the hypothesized ether drift. In view of recent comments by Carnahan[2] on the interpretation of this experiment, there may be some point in describing this work.

Our ether drift theory may be defined in the following way. We assume first that Maxwell's equations hold in the ether frame. Secondly we assume that charge and current densities, fields, and coordinates in a frame moving with respect to the ether are related to the corresponding quantities in the ether frame by means of a Lorentz transformation. Explicitly, this means (in mks units)

$$\begin{aligned} \boldsymbol{j}(\boldsymbol{r}, t) &= \boldsymbol{j}'(\boldsymbol{r}', t') + \lambda \boldsymbol{u} \rho'(\boldsymbol{r}', t') \\ \rho(\boldsymbol{r}, t) &= \rho'(\boldsymbol{r}', t') + \lambda \boldsymbol{u} \cdot \boldsymbol{j}'(\boldsymbol{r}', t')/c_0^2 \\ \boldsymbol{E}(\boldsymbol{r}, t) &= \boldsymbol{E}'(\boldsymbol{r}', t') - \lambda \boldsymbol{u} \times \boldsymbol{B}'(\boldsymbol{r}', t') \\ \boldsymbol{B}(\boldsymbol{r}, t) &= \boldsymbol{B}'(\boldsymbol{r}', t') + \lambda \boldsymbol{u} \times \boldsymbol{E}'(\boldsymbol{r}', t')/c_0^2 \quad (1) \end{aligned}$$

with

$$\boldsymbol{r}' = \boldsymbol{r} - \lambda \boldsymbol{u} t, \qquad t' = t - \lambda \boldsymbol{u} \cdot \boldsymbol{r}/c_0^2.$$

In the above equations primed quantities refer to the local ether frame, assumed to be moving with velocity $\lambda \boldsymbol{u}$ with respect to the laboratory frame, while unprimed quantities refer to the laboratory frame. Quantities of higher than the first order in $\lambda \boldsymbol{u}$ have been neglected in (1) and will be neglected throughout our discussion. We are supposing $\boldsymbol{u}$ to be the velocity of, let us say, an intergalactic ether with respect to the laboratory frame from which the local ether velocity $\lambda \boldsymbol{u}$ may differ due to an ether drag effect. Our theory differs from a Lorentz invariant theory in that we do not require the velocity c_0 to be equal to the local velocity of light (denoted by c). In this way (1) becomes compatible with a variety of viewpoints. If one takes $c_0 = \infty$ one has a prerelativity ether drift theory. On the other hand it is certainly more satisfactory considering our current knowledge to recognize at least the approximate validity of special relativity and expect c_0 and c to be approximately equal. A theory with c_0 different from c must clearly be equivalent to a discussion of Maxwell's equations within a moving material medium. One may think of the medium as being a local phenomenon (say solar, or galactic) or all pervasive, possibly with a local drag coefficient as well. It will become apparent in the course of the discussion that all conclusions to be drawn are expressible in terms of a theory with $c_0 = \infty$ and λ replaced by an effective value λ_e. Thus it is possible to regard all of the above points of view as experimentally equivalent to a prerelativistic ether drift theory.

The discussions of CBHT and Moeller[3] make no explicit reference to the interaction of the electromagnetic field with the cavity walls.[4] While it may be surmised from their conclusions that they had a correct description of this interaction in mind, a derivation of their result based upon a complete theory of the cavity modes may be easier to understand. We shall see that their result can be obtained in a very simple and general way.

The transformation equations (1) are not immediately applicable to the solution of the cavity mode problem. Since the cavity walls are moving in the ether frame, the problem of determining the fields $\boldsymbol{E}_0$, $\boldsymbol{B}_0$, is not especially inviting. Furthermore the harmonic time dependence which we require in the laboratory frame is not preserved in the transformations. It is much simpler to discuss the problem in the laboratory frame with stationary cavity walls. For this purpose we require the modified form of Maxwell's equations in the laboratory frame which (1) implies. These may easily be seen to be

$$\nabla \cdot \boldsymbol{B} = 0$$

$$\nabla \times \boldsymbol{E} = -\dot{\boldsymbol{B}}$$

$$\nabla \cdot \boldsymbol{D} = \rho, \text{ with } \boldsymbol{D} = \epsilon_0(\boldsymbol{E} + \lambda_e \boldsymbol{u} \times \boldsymbol{B}). \quad (2)$$

$$\nabla \times \boldsymbol{B} = \mu_0(\boldsymbol{j} + \dot{\boldsymbol{D}} - \lambda_e \nabla \times (\boldsymbol{u} \times \boldsymbol{D}))$$

with

$$\lambda_e = \lambda[1 - (c^2/c_0^2)], \qquad c^2 = 1/\mu_0\epsilon_0.$$

We now seek solutions of (2) with harmonic time dependence satisfying the conditions $\boldsymbol{E} \times \hat{\boldsymbol{n}} = \boldsymbol{B} \cdot \hat{\boldsymbol{n}} = 0$ at the boundaries of the cavity. Let $\boldsymbol{E}_0(\boldsymbol{r}) \exp i\omega t$, $\boldsymbol{B}_0(\boldsymbol{r}) \exp i\omega t$ represent any solutions of Maxwell's equations with harmonic time dependence. Then one may readily verify that, to order $\boldsymbol{\beta} = \boldsymbol{u}/c$,

$$\begin{aligned} \boldsymbol{E}(\boldsymbol{r}, t) &= \boldsymbol{E}_0(\boldsymbol{r}) \exp i(\omega t + k\lambda_e \boldsymbol{\beta} \cdot \boldsymbol{r}) \\ \boldsymbol{B}(\boldsymbol{r}, t) &= \boldsymbol{B}_0(\boldsymbol{r}) \exp i(\omega t + k\lambda_e \boldsymbol{\beta} \cdot \boldsymbol{r}) \\ &\quad - \lambda_e \boldsymbol{\beta} \times \boldsymbol{E}(\boldsymbol{r}, t)/c, \quad (3) \end{aligned}$$

with

$$k = \omega/c$$

are solutions of (2). We therefore take $\boldsymbol{E}_0(\boldsymbol{r})$, $\boldsymbol{B}_0(\boldsymbol{r})$ to be the fields of the cavity mode in the absence of an ether drift. The boundary conditions $\boldsymbol{E}_0 \times \hat{\boldsymbol{n}} = \boldsymbol{B}_0 \cdot \hat{\boldsymbol{n}} = 0$ satisfied by these fields guarantee that the fields given by (3) satisfy the proper analogous boundary conditions and are therefore the appropriate solutions to apply to the cavity in the presence of the postulated ether drift.

We now consider the time dependence of the electric field acting upon a molecular system translating through the cavity with velocity $\boldsymbol{v}$. In the rest frame of the molecular system we have

$$\begin{aligned} &\boldsymbol{E}_m(\boldsymbol{r}_0, t) \\ &= \boldsymbol{E}(\boldsymbol{r}_0 + \boldsymbol{v}t, t + \boldsymbol{v} \cdot \boldsymbol{r}_0/c_0^2) \\ &\quad + \boldsymbol{v} \times \boldsymbol{B}(\boldsymbol{r}_0 + \boldsymbol{v}t, t + \boldsymbol{v} \cdot \boldsymbol{r}_0/c_0^2) \\ &= (\boldsymbol{E}_0(\boldsymbol{r}_0 + \boldsymbol{v}t) + \boldsymbol{v} \times \boldsymbol{B}_0(\boldsymbol{r}_0 + \boldsymbol{v}t)) \\ &\times \exp[i\omega t - \boldsymbol{k} \cdot \boldsymbol{r}_0 - k\lambda_e \boldsymbol{\beta} \cdot \boldsymbol{v}t + \omega\lambda_e \boldsymbol{v} \cdot \boldsymbol{r}_0/c^2] \quad (4) \end{aligned}$$

where $\boldsymbol{r}_0$ is the position of the system at $t = 0$. If the frequency spectrum of this signal is given by $\tilde{\boldsymbol{E}}(\nu)$ for $\boldsymbol{\beta} = 0$, it will be given by $\tilde{\boldsymbol{E}}(\nu - k\lambda_e \boldsymbol{\beta} \cdot \boldsymbol{v})$ for $\boldsymbol{\beta} \neq 0$ (apart from an irrelevant phase factor). Since the molecular response to the stimulating electric field is by far the dominant frequency-controlling element,[5] the oscillation frequency will be increased by $k\lambda_e \boldsymbol{\beta} \cdot \boldsymbol{v} = \lambda_e \boldsymbol{u} \cdot \boldsymbol{v}/c^2$ in agreement with the interpretation of CBHT and the discussion of Moeller. We note that the result depends only upon the combination λ_e and not upon λ and c_0 individually, thus confirming our comment about the experimental equivalence of the various viewpoints previously discussed. The result is evidently independent of the structure of the cavity and the mode chosen.

It is a pleasure to acknowledge extensive discussions of these questions with Prof. C. H. Townes and Dr. D. M. Brink.

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Author's Comment[6]

Profs. Kroll and Lamb are to be complimented on providing the first really adequate theoretical background for the Cedarholm-Townes[1] experiment. They have convinced me of my error in assuming that a beam-type maser cannot oscillate in a mode in which the wavefronts are inclined to the direction of the molecular beam, in the presence of an ether drift.

Having conceded this point, where are we? The parallel mode of oscillation as described in my note[2] is still a valid mode for an oscillator, if it can supply the slight losses

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* Received December 1, 1961.

[1] J. P. Cedarholm, G. F. Bland, B. L. Havens, and C. H. Townes, "New experimental test of special relativity," *Phys. Rev. Lett.*, vol. 1, p. 342; November, 1958.

[2] C. W. Carnahan, "Masers, lasers, and the ether drift?," Proc. IRE, vol. 49, pp. 1576–1577; October, 1961.

[3] C. Moeller, "On the possibility of terrestrial tests of the general theory of relativity," *Nuovo Cim.* (Suppl.), vol. 6, p. 381; 1957.

[4] The error in Carnahan's argument arises from a neglect of the effect of the cavity walls. The CBHT cavity is designed to oscillate in a mode for which the fields do not vary in the direction of the presumed ether velocity, corresponding, from the point of view of a plane-wave analysis, to waves moving perpendicularly to the ether velocity. The electric field lines are also parallel to the ether velocity and perpendicular to the end walls of the cavity. Carnahan notes that the CBHT argument requires that the ether drift cause the wavefronts to tilt and objects that the authors present no mechanism which might cause such a tilt. It is clear, however, that to an observer fixed in the ether it would appear that the end walls were moving through the magnetic field of the cavity mode, and he would expect that the electric field lines would have to tilt in order to cancel that part of the resultant Lorentz force tangential to the end walls. The tilting of the electric field lines in the ether frame requires that the wavefronts also tilt. Transformation to the laboratory frame by means of (1) then removes the tilt from the electric field lines but not, in general, from the wavefronts. Only in the special case $c = c_0$ is the tilt from the wavefronts also removed. The detailed implications of this readjustment are most easily seen from the theory presented in the text, but one may regard the Lorentz force as providing the mechanism sought by Carnahan.

[5] See, for example, W. E. Lamb, Jr., "Lectures in Theoretical Physics," Interscience Publishers, Inc., New York, N. Y., vol. 2; 1960. (See especially pp. 455–461.) The theory given in this reference can be trivially adapted to the fields given by (3) for a complete and explicit derivation of the frequency shift.

[6] Received March 20, 1962.

caused by such a "walk-off" mode. The original theory of the Cedarholm-Townes experiment, confirmed by Kroll and Lamb, predicts a shift of cavity frequency in the presence of an ether drift, the emission frequency of the ammonia molecule remaining the same. Because of the Doppler shift due to the inclined wavefronts, the molecule sees its characteristic frequency regardless of ether drift.

In the parallel mode of oscillation there is a slight decrease in the Q of the cavity in the presence of ether drift because some of the energy leaves the cavity in the direction of the drift. The cavity is detuned slightly, and this detuning, divided by the stabilization factor of the maser, is the amount by which the emitted molecular frequency must change to support this mode.

Since the experiment itself cannot tell us in which mode the oscillation occurred, our only recourse is to look at the numbers involved, in the hope of finding which mode requires the least readjustment of the oscillation parameters in the presence of ether drift.

In the actual experiment, the following quantities are pertinent: u, the molecular velocity, was 0.6 km/sec, the length l of the cavity was 10 cm, the Q of the cavity, Q_c, was 10^4, and f_0, the ammonia frequency, about 24×10^6 cps, and the stabilization factor S about 2000. The maximum velocity of ether drift allowed by the results of the experiment was $v = 1.5 \times 10^3$ cm/sec.

Considering the inclined mode first, the predicted frequency shift due to the ether drift given above would be, for a 180-degree rotation, $(2uv/c^2)f_0 = 1.8 \times 10^{-13} f_0$, or 0.0042 cps.

For the parallel mode, the Q_d connected with the losses due to energy walk-off is $Q_d = 2\pi f_0 l/v \cong 10^9$. This has to be combined with the cavity Q_c, to give a resultant $Q_T = Q_c/(1+10^{-5})$. Using the formula for the resonant frequency of a cavity with losses, $f' = f(1-1/8Q^2)^{1/2}$, and a little algebra, we arrive at the detuning of the cavity as $0.25 \times 10^{-13} f_0$, which is less by a factor of seven than the shift of frequency due to the inclined mode. Dividing the detuning by the stabilization factor S yields $0.125 \times 10^{-16} f_0$ as the required change in the emitted molecular frequency to support the parallel mode. This last value is so small compared with the natural width of the ammonia line that it is meaningless, beside being far below the precision of the experiment.

Thus we see that the parallel mode of oscillation involves practically no readjustment of oscillator parameters, certainly less by orders of magnitude than that required by the inclined mode. We conclude, then, that the oscillator will continue in the parallel mode with an inappreciable change of frequency, regardless of ether drift.

The Cedarholm-Townes experiment found a frequency shift of 1.08 cps when the masers were rotated through 180 degrees. This was ascribed to local magnetic effects and no attempt was made to shield the apparatus. The absence of ether drift was inferred from the constancy of this shift as the earth changed its direction in space. It is unfortunate that this experiment is now described in current texts as a repetition of the Michelson-Morley experiment, with a precision at least four or five orders of magnitude greater. This is not true—Michelson and Morley spent about a year floating their apparatus on a pool of mercury so that it could be rotated without change, and another year observing the absence of fringe shifts. The same procedure was employed later by Joos with a tenfold increase in precision. The negative result of these experiments has never been seriously challenged. The Cedarholm-Townes experiment, on the other hand, relies on the observation of an uncontrolled and accidental magnetic variation, and now it appears that the theory is on shaky ground.

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Time Coherence in Ruby Lasers*

The concept of coherence time[1] is of importance for use of lasers in communications, since random fluctuations of the photons within a single cell of phase space constitute a noise source. The magnitude of these fluctuations as perceived by a photoelectric detector is a function of the coherence time.[2,3] In addition, the results of such basic physics experiments as photoelectric mixing using a laser[4] and a repetition of the Hanbury-Brown and Twiss experiment[5] with a laser will depend on the coherence time of the laser employed.

It has been generally assumed previously that the coherence time T is equal to the reciprocal of the bandwidth ($\Delta\nu$) of the laser emission. The bandwidth of laser emission is of the order of 10^9 cps.[6,7] This leads to assuming $T \approx 10^{-9}$ sec.

The argument by which we are led to $T \approx 1/\Delta\nu$ in the case of incoherent light sources is, however, no longer valid for laser emission. For incoherent light sources, the time interval over which a given set of atoms is emitting is given by the uncertainty principle as $1/\Delta\nu$. For times short compared to $1/\Delta\nu$ the set of atoms emitting is essentially unchanged and the radiation is coherent. For times long compared to $1/\Delta\nu$ the set of atoms emitting has changed in an unpredictable manner, the phase of the radiation has changed erratically, and the radiation is incoherent.

For laser emission, however, the fact that the set of atoms emitting changes from time to time does not mean incoherence. The emission from one atom no longer occurs independently of the emission from surrounding atoms. The radiation stored in the resonant cavity stimulates the emission so that the emitted radiation will be in phase with that already present. The process of stimulated emission ties together acts of emission occurring at different times so that the output is coherent.

The total linewidth then is not determined by the uncertainty principle. The linewidth arises from the fact that numerous modes of the resonant cavity are excited in one laser burst. Although each mode has a narrow width, the total emission will be much broader. We have observed the presence of many off-axis modes in the ruby laser in far-field pictures of the laser emission taken through a 300-mm focal length lens. These modes arise in the ruby crystal itself from stimulated emission radiation traveling at an angle to the rod axis, *i.e.*, off-axis Fabry-Perot modes. The half width of these modes was measured to be about 4×10^{-3} cm^{-1} or about 1.2×10^8 cps. Thus the coherence time can be no shorter than about 10^{-8} sec. However, this measurement does not determine the coherence time, since the half width[8] of the Fabry-Perot cavity formed by the ruby end surfaces (length 3 in) is of the order of 2×10^{-3} cm^{-1}. Thus, the measured value of the half width of a mode could be determined by the instrument, rather than by fundamental considerations. Other investigators[9] who found a half width of the axial laser modes of about 10^{-3} cm^{-1} with an external Fabry-Perot interferometer were also working near their instrumental resolution.

Photomixing experiments[10] also indicate a coherence time longer than $1/\Delta\nu$. The presence of beats at multiples of 600 Mc indicates that the radiation field must remain coherent for a time long compared to $1/600 \times 10^6 = 1.6 \times 10^{-9}$ sec, for otherwise the beats would be destroyed.

It is tempting to speculate that the output remains coherent over the duration of a microsecond relaxation oscillation.

The direct measurement of coherence time in a ruby laser suggests a number of possible experiments, for example:

1) Direct photography of interference patterns. The beam should produce interference patterns in the near field that persist for the duration of the coherence time. If T approaches 10^{-6} sec, these patterns should be possible to photograph directly with high speed cameras.
2) Observation of statistical fluctua-

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* Received, May 4, 1962.

[1] A. T. Forrester, "On coherence properties of light waves," *Am. J. Phys.*, vol. 24, pp. 192–196; April, 1956.

[2] L. Mandel, "Fluctuations of photon beams and their correlations" *Proc. Phys. Soc.* (*London*), vol. 72, pp. 1037–1048; December, 1958.

[3] L. Mandel, "Fluctuations of photon beams: the distribution of the photo-electrons," *Proc. Phys. Soc.* (*London*), vol. 74, pp. 233–243; September, 1959.

[4] A. T. Forrester, "Photoelectric mixing as a spectroscopic tool," *J. Opt. Soc. Am.*, vol. 51, pp. 253–259; March, 1961.

[5] R. Hanbury-Brown and R. Q. Twiss, "Correlation between photons in two coherent beams of light," *Nature*, vol. 177, pp. 27–29; January 7, 1956.

[6] R. J. Collins, *et al.*, "Coherence, narrowing, directionality, and relaxation oscillations in the light from ruby," *Phys. Rev. Lett.*, vol. 5, p. 303; October 1, 1960.

[7] A. L. Schawlow, "Infrared and optical masers," *The Solid State Journal*, vol. 2, pp. 21–29; June, 1961.

[8] S. Tolansky, "High Resolution Spectroscopy," Pitman Publ. Corp., New York, N. Y., ch. 9; 1947.

[9] T. H. Maiman, *et al.*, "Stimulated optical emission in fluorescent solids," *Phys. Rev.*, vol. 123, p. 1151; August 15, 1961.

[10] B. J. McMurtry and A. E. Siegman, "Photomixing experiments with a ruby optical maser and a traveling-wave microwave phototube," *Applied Optics*, vol. 1, pp. 51–53; January, 1962.

tions. Within one cell in phase space (*i.e.*, for a time shorter than the coherence time at a point in the beam), the emission of photoelectrons from a photoemissive surface shows fluctuations characteristic of the Bose-Einstein nature of the photons.[2,3] For an observation time containing many cells of phase space it can be shown that the fluctuations take on the classical Maxwell-Boltzmann form. Thus, a multiplier phototube used in a circuit with fast-time constants and operated at a gain such as to yield a measurable pulse from a single photoelectron placed in a laser beam filtered so that rate of photoelectron emission is small enough that individual pulses may be observed, can be employed to study the statistical character of the pulse distribution for observation times in the range 10^{-9} to 10^{-6} sec. The Bose-Einstein character of the radiation should be directly observable in observation times short compared to T.

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Experiments on a Quarter-Wave Coupled Three Esaki Diodes Microwave Amplifier*

The construction of the quarter-wave coupled three Esaki diodes amplifier is shown in Fig. 1. Where $-g_a$ and $-g_b$ are normalized negative conductances of the Esaki diodes, C_a and C_b are normalized capacitances of the tank circuits which should resonate at the same frequency f_0, and z_1 is a normalized impedance of the quarter-wave coupling lines.

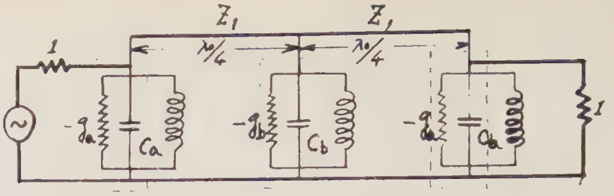

Fig. 1 Equivalent circuit of the quarter-wave coupled three Esaki diodes amplifier.

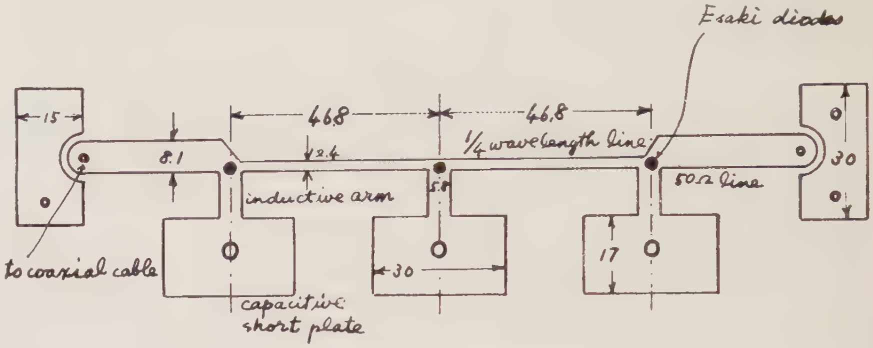

Fig. 2—Construction of the amplifier.

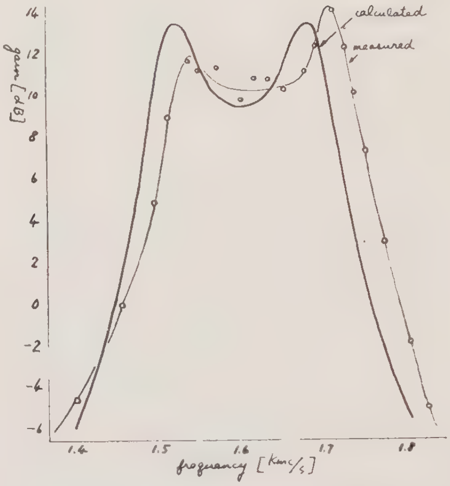

Fig. 3—Measured and calculated gain in db using the parameters as $z_1=1.9$, $-R=125\ \Omega$, $C_a=C_b=7$ pF.

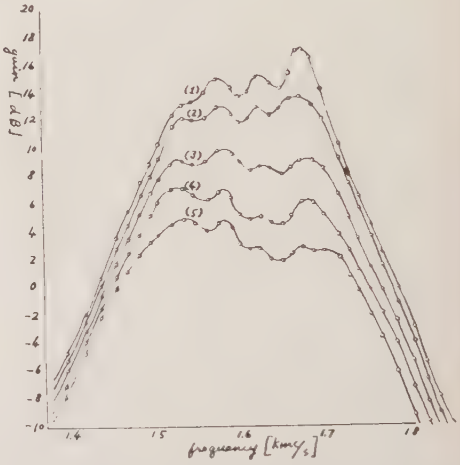

Fig. 4—Measured gain in db of a slightly modified amplifier. DC bias voltages of the diodes are 205 mv (1), 210 mv (2), 220 mv (3), 230 mv (4) and 240 mv (5).

In order to consider frequency characteristics of the quarter-wave lines, a narrow bandwidth assumption was made and then the power gain G of the amplifier is calculated as[1]

$$G = G_0/[(1+X)\{(\mu X-1)^2+\lambda X\}] \quad (1)$$

where

$$G_0 = (1-g_a)^{-2}\{z_1^2(g_b/2)(1-g_a)-1\}^{-2};$$

center gain,

$X=K(\Delta\omega/\omega_0)^2$, μ, λ, and K are constant determined by the circuit parameters.

This amplifier is stable if (2) is satisfied.

$$(\pi/2)(1-g_a-g_b/2) + \omega_0 z_1\{C_b(1-g_a)-C_a g_b\} > 0 \cdots. \quad (2)$$

The gain bandwidth product is expressed under a matched condition as

$$G_0^{1/2}\Delta f = (\epsilon/\pi)G_0^{1/2}/[(G_0^{1/2}-1) \cdot\{2C_a+1/(4z_1 f_0)\}] \cdots. \quad (3)$$

The value of ϵ is changed from 0 to ∞, but it will remain from 0.7 to 1.2 by the ordinary choice of the circuit parameters. Under mismatched conditions, it is slightly modified.

We made the amplifier using three IT1103 Esaki diodes (produced by Sony Company) having nearly the same parameters and an open strip line of 50 Ω characteristic impedance as shown in Fig. 2.

The measured and calculated values are shown in Fig. 3. The maximum negative conductance $-g$ of 1T1103 is slightly higher than the value restricted by (2), so we must adjust the bias voltage so as to get a proper value of $-g$ obtaining a stable amplification. The measured and calculated results are in rough agreement.

This original circuit is slightly modified to obtain rather optimum gain frequency characteristics. The measured results are shown in Fig. 4. The power gain was 12 db at $f_0=1.6$ kMc and bandwidth 200 Mc, that is, ±6 per cent of f_0. Off band rejection was greater than -15 db which was measured in saturation conditions, so more rejection might be really obtained.

The noise figure of this amplifier is also calculated and, according to this result, we could estimate the noise figure to be 3 to 4 db with proper choice of the parameters.

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* Received March 27, 1962; revised manuscript received April 16, 1962.

[1] In the analysis, the transmission angles of the coupling lines are not constant as $\pi/2$ except at f_0. Makimoto (footnote 2) calculated the power gain assuming the angle was constant.

[2] T. Makimoto, "A cavity-filter type negative resistance amplifier circuits," *Conv. Record of Inst. of Elect. Comm. Engrg. of Japan*, p. 174; November, 1961.

Continuous Gas Maser Operation in the Visible*

We have made some spectral studies of the helium-neon gas discharge plasma first described by Javan[1] and later shown by Javan, Bennett and Herriot[2] to exhibit maser action in the 1-micron region. The function of the helium is to enhance the population of the neon 2*s* levels above that which can normally be produced in a pure neon discharge. The enhancement mechanism is attributed to a resonance transfer of excitation energy from triplet helium metastable to ground state neon atoms.

The infrared transitions at ~11,500 Å from the $2s \rightarrow 2p$ levels in neon observed by Javan, *et al.*[2] are shown schematically (wavy line) in Fig. 1. The nonradiative transitions leading to enhancement of the 2*s* neon levels are denoted by solid lines. The measurements we have made of the relative intensity of other neon transitions in both He-Ne and pure Ne discharges have led us to believe that enhancement of the 3*s* neon levels in a similar He-Ne discharge is occurring by a mechanism identical to that described by Javan, except that the transfer occurs from the singlet helium metastable as indicated by the dashed line.

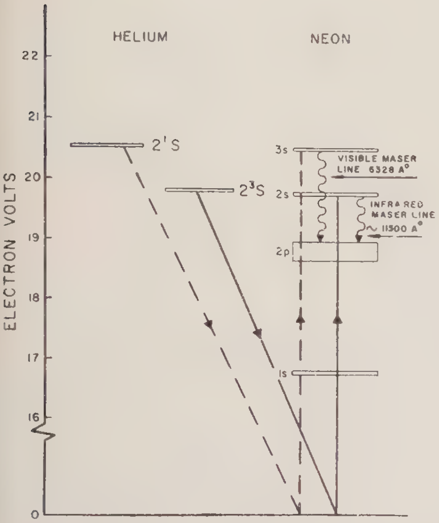

Fig. 1—Energy level diagram for helium and neon.

Transmission measurements to determine whether the enhancement was sufficient to create population inversion between the 3*s* and 2*p* levels showed that the plasma (at a total pressure of 1.5 mm Hg, He-Ne ratio ~10:1) was ~98 per cent transparent at 6328 Å corresponding to the $3s_2 \rightarrow 2p_4$ neon transition. However, the results were not deemed sufficiently precise to rule out inversion, consequently a near-confocal optical cavity with highly reflecting mirrors (peak reflectance at ~6350Å) was fabricated in an attempt to confirm inversion by observing maser action.

The maser discharge tube (~1.2 meters long; ~0.7 cm diameter) had Brewster windows similar to those described by Rigrod, *et al.*[3] The plasma (He-Ne ratio 10:1 with total pressure ~0.7 mm Hg) was excited from a dc power supply at ~1700 volts and from 10 to 50 ma. The discharge current was supplied by a tungsten thermionic cathode located in an appendage on the side of the maser tube.

At currents in excess of ~25 ma, maser oscillation in the neon line at 6328 Å was observed. The emergent beam, impinging on a white screen, was bright enough to be visible in a lighted room. Mode patterns of both high and low order, similar to those predicted by Fox and Li,[4] and Boyd and Gordon[5] were seen. Examination of the output signal from a high-frequency photodiode detector placed at the beam focus, indicated that the maser output was free of relaxation oscillations, of the type commonly seen in ruby optical masers, at least up to the frequency limit of the oscilloscope (estimated at ~10 Mc). The output power from each end of the maser, as measured by a calibrated Eppley thermopile was found to be ~0.1 mw. No attempt has been made to optimize the power output by changing either the He-Ne ratio or the total pressure.

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* Received June 1, 1962.

[1] A. Javan, "Quantum Electronics," C. H. Townes, Ed., Columbia University Press, New York, N. Y., p. 564; 1960.

[2] A. Javan, W. R. Bennett, Jr., and D. R. Herriot, "Population inversion and continuous maser oscillation in a gas discharge containing a He-Ne mixture," *Phys. Rev. Lett.*, vol. 6, pp. 106–110; February, 1961.

[3] W. W. Rigrod, H. Kogelnik, D. Brangaccio and D. R. Herriot, "Gaseous optical maser with external concave mirrors," *J. Appl. Phys.*, vol. 33, pp. 743–744; February, 1962.

[4] A. G. Fox and T. Li, "Resonant modes in a maser interferometer," *Bell Sys. Tech. J.*, vol. 60, pp. 453–488; March, 1961.

[5] G. D. Boyd and J. P. Gordon, "Confocal multimode resonator for millimeter through optical wavelength masers," *Bell Sys. Tech. J.*, vol. 60, pp. 489–508; March, 1961.

Tunable Millimeter Traveling-Wave Maser Operation*

Prototype sections of a low-noise solid-state maser amplifier have been operated at signal frequencies up to 41 kMc. This K_a-band maser is of the traveling-wave type, has an extremely large tuning range, incorporates ferrite isolators to obtain high gain stability, and uses pump frequencies in the 75 kMc region.

Design Considerations

CW maser operation in the millimeter-wave region is presently dependent upon the availability of high-frequency pump sources. Three-level maser operation in general requires that the pump frequency be greater than twice the signal frequency, *i.e.*, $f_p > 2f_s$. Four-level operation, using push-pull pumping, offers the significant advantages of a relaxed pump frequency requirement ($f_p > f_s$), and higher population inversion ratio for given pump and signal frequencies. Thus, this relaxed pump frequency condition permits the operation of millimeter-wave masers to frequencies almost as high as the frequency of available coherent sources, not considering special techniques.[1,2] To demonstrate this, we have obtained maser action at a signal frequency of 40 kMc, using a pump frequency of only 43 kMc, and an applied magnetic field of 700 oersteds, using push-pull pumped chromium-doped titania as the active maser crystal at 4.2°K.

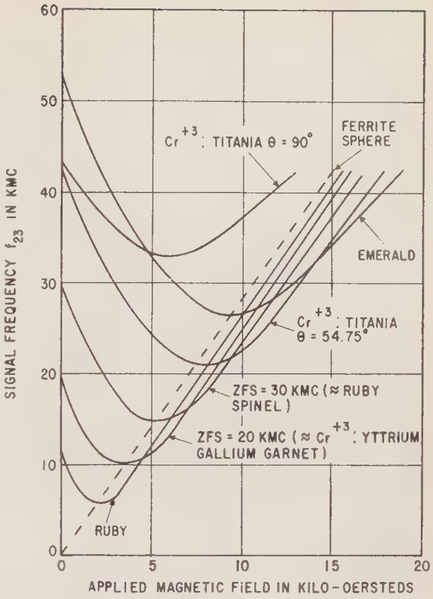

Fig. 1—Comparison of various push-pull-pumped maser materials.

Cr^{3+}-doped crystals have the advantage of symmetry in their energy levels at certain crystal orientations, permitting push-pull pumping over extended signal frequency ranges. Fig. 1 shows signal frequency as a function of applied magnetic field for several Cr^{3+}-doped maser crystals with varying zero-field-splittings (ZFS). As Fig. 1 shows, in the case of Cr^{3+}-doped titania for $\theta \rightarrow 90°$, the presence of the axial (E) term in the Spin Hamiltonian is useful in minimizing magnetic field requirements in the high-field region. The high-field region has the advantages of 1) high gain per unit length, and 2) convenient traveling-wave maser operation, since overlap with a ferrimagnetic isolator material is obtainable by adjusting the ferrite demagnetizing factors (Fig. 1). Cr^{3+}-doped titania[3,4] has the addi-

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[1] J. Minkowski, "Cross relaxation effect of Cr and Fe in $K_3(Co, Cr, Fe)(CN)_6$," *Phys. Rev.*, vol. 119, pp. 1577–1578; 1960.

[2] F. Arams, "Maser operation at signal frequencies higher than pump frequency," IRE Trans. on Microwave Theory and Techniques, vol. MTT-9, pp. 68–72; January, 1961.

[3] H. Gerritsen, S. Harrison and H. Lewis, "Chromium-doped titania as a maser material," *J. Appl. Phys.*, vol. 31, pp. 1566–1571; September, 1960.

[4] D. Devor, "Fine Structure Levels and Transition Probabilities of Cr^{3+} in TiO_2 (Rutile)," Hughes Res. Labs., Calif., Res. Rept. No. 148; May, 1960.

tional attribute of a relatively-high slowing factor, due to its high dielectric constant (greater than 100), without resorting to filter structures. Three-level operation has previously been obtained.[5]

Experimental Results

A two-port traveling-wave maser structure consisting of waveguide loaded with titania, and therefore substantially reduced in size, was matched to standard waveguide over the 26 to 40 kMc band.

Maser action was obtained in the low-magnetic-field region over the entire band from 25 to 40 kMc with pump frequencies from 43 to 47.3 kMc and magnetic fields from 0.7 to 5.2 kilo-oersteds (Fig. 2). The magnetic field was oriented at $\theta = 54.7°$ in the AC plane of the maser crystal, where the two magnetic complexes of Cr^{3+} in TiO_2 are aligned, thereby doubling the db of electronic gain.

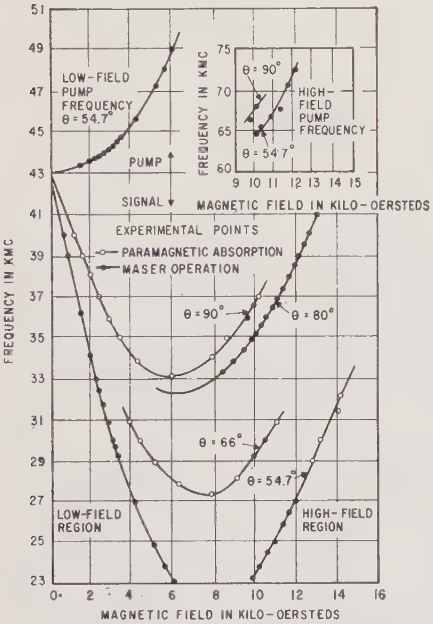
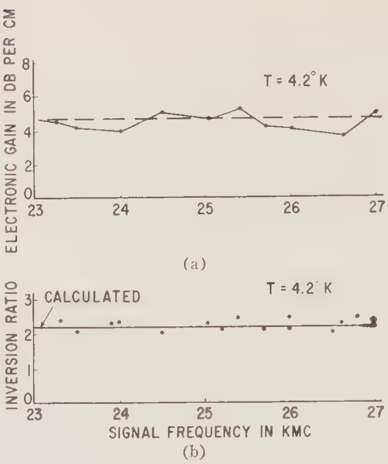


Fig. 2—Experimental operating points.

Population inversion was also obtained using the above crystal orientation at high magnetic fields where higher gains, due to the higher pump frequency, are available. As shown in Fig. 3(a), electronic gains averaging 4.4 db/cm from 23 to 27 kMc were obtained at 4.2°K. The electronic gain increased to 10.5 db/cm at 1.7°K. The measured population inversion correlated well with the calculated value of 2.2 [Fig. 3(b)]. Pump frequencies used were from 64 to 73 kMc.

Traveling-wave maser action over the entire 33.5 to 41 kMc band was obtained using a $\theta = 80°$ crystal, and pump frequencies from 62 to 82 kMc (Fig. 2). Electronic gains of 6.5 db/cm, and a population inversion ratio averaging 1.5, were obtained at 1.7°K. Ferrite isolators were successfully incorporated into the TWM structure to insure stable operation. The ferrite overlaps the TiO_2 tuning curve from 34 to 42 kMc at liquid helium temperatures. The isolator losses are less than 0.5 db/cm in the forward direction, and over 30 db/cm in the reverse direction.



(a)

(b)

Fig. 3—Electronic gain and population inversion ratio vs signal frequency.

Conclusion

Stable traveling-wave maser operation has been obtained over very large tuning ranges in K_a-band using Cr^{3+}-doped titania as the active material. The tuning range can be varied by suitably selecting the crystal orientation. The techniques employed are also believed to be applicable at much higher frequencies. Further work is in progress.

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[5] H. Gerritsen and H. Lewis, "Operation of a chromium-doped titania maser," *J. Appl. Phys.*, vol. 31, pp. 608–609; March, 1960. Also, E. S. Sabisky and H. J. Gerritsen, "A traveling-wave maser using chromium-doped rutile," Proc. IRE (*Correspondence*), vol. 49, pp. 1329–1330; August, 1961.

Correction to "The Field Induced by Eddy Currents in a Semi-Infinite Solid"*

With regard to my correspondence,[1] J. Dokas of the Electronics Division, Westinghouse Electric Corporation, Baltimore, Md. has communicated the following exact form of (5):

$$B_n = B_0(1 - e^{\lambda^2} \operatorname{erfc} \lambda).$$

This is obtained by the substitution

$$e^{-(\eta-\eta')^2} = \frac{1}{\sqrt{\pi}} \int_0^\infty e^{-t^2/4} \cos(\eta - \eta')t\,dt,$$

and the use of

$$\int_{-\infty}^{\infty} \frac{\cos \eta t}{\eta^2 + \xi^2}\, d\eta = \frac{\pi}{\xi} e^{-\zeta\iota}.$$

Further, an asymptotic series for (5) becomes, then,

$$B_h = B_0\left[1 - \frac{1}{\sqrt{\pi}\lambda}\left(1 - \frac{1}{2\lambda^2} + \frac{1\cdot 3}{(2\lambda^2)^2} - \frac{1\cdot 3\cdot 5}{(2\lambda^2)^3} + \cdots\right)\right]$$

This does not compare with (6), which is in error. I have mistakenly used,

$$\int_{-\infty}^{\infty}\left(\frac{\eta'}{\lambda}\right)^{2k} e^{-\eta'^2+2\eta\eta'}d\eta' = \frac{\sqrt{\pi}}{\lambda^{2k}2^{2k-1}}\left(\frac{d}{d\eta}\right)^{2k-1} \eta e^{-\eta^2}.$$

The exponential on the right should have a positive sign. It then becomes impossible to evaluate the series as I have done.

The author wishes to thank J. Dokas for sending his result, and asks the indulgence of the IRE for this error.

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* Received February 21, 1962.

[1] R. W. Peterson, "The field induced by eddy currents in a semi-infinite solid," Proc. IRE (*Correspondence*), vol. 50, pp. 88–89; January, 1962.

X-Band Operation of *S*-Band Esaki Diodes*

The purpose of this communication is to report the experimental results of the behavior of *S*-band Esaki diodes operated in the *X* band. The *S*-band Esaki diode, a 1N3219A, was mounted in the *X*-band tapered waveguide, shown in Fig. 1.

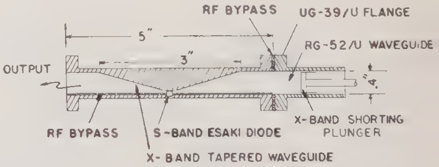

Fig. 1—Cross-sectional view of *S*-band Esaki diode mounted in an *X*-band tapered waveguide.

The frequency of oscillation was verified by three different methods; namely, by the RWT receiver (tuning range 2–75 kMc), the Microline coaxial frequency meter Model 126, and the shorting plunger shown in Fig. 1. For example, when the receiver frequency dial indicated an output at 9.408 kMc, the coaxial frequency meter indicated 9.410 kMc and the waveguide wavelength measured using the shorting plunger was 1.770 inches which corresponds to 9.351 kMc. The output power of the diode was large enough to allow for accurate frequency measurements, as shown in Fig. 2. Fig. 3 indicates

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* Received April 2, 1962; revised manuscript received April 16, 1962.

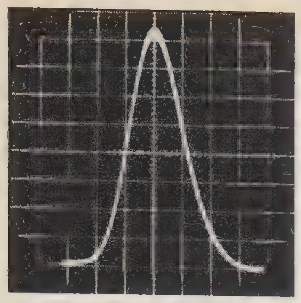

Fig. 2—An example of detected output power at −23 dbm with dc bias of 200 mv and an oscillation frequency of 8.6 kMc.

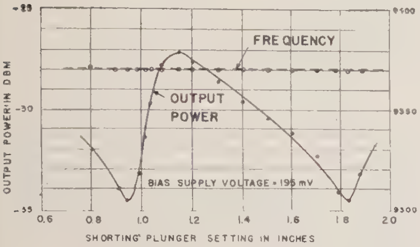

Fig. 3—Effect of the shorting plunger.

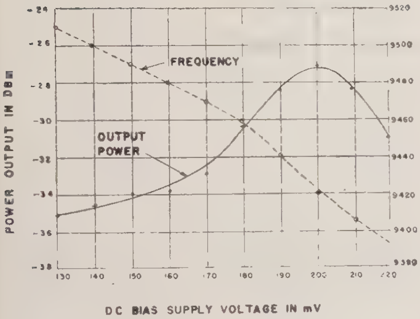

Fig. 4—Effect of dc bias supply voltage.

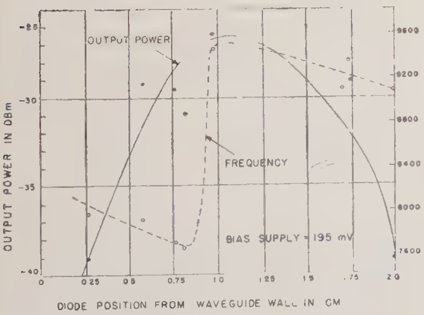

Fig. 5—Effect of diode mounting position.

that the frequency of oscillation remained stable during circuit impedance variation. Bias supply voltage had a significant influence on the output power and frequency as shown in Fig. 4. The output power and frequency were also influenced by the mounting position of the diode as shown in Fig. 5. Long time stability of the *X*-band operation of the *S*-band diode was very good.

Recently it was reported that the Esaki diode demonstrated very high frequency adaptability at *F* band in a laboratory test.[1] Microwave Esaki diodes are commercially available for frequencies as high as *V* band.[2] However, these high-frequency diodes are very expensive at present. The technique shown in this article indicates the possibility of extending the upper frequency limit of the less expensive commercially available Esaki diodes.

The authors thank J. E. Billo, J. A. Stephancin, S. Krupnik, Jr., and G. Raue for their assistance.

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[1] C. A. Burrus, "Millimeter wave Esaki diode oscillators," Proc. IRE (*Correspondence*), vol. 48, p. 2024; December, 1960.

[2] International Microwave Corporation, "Tunnel Diodes," *Microwave J.* (Advertisement), vol. 5, p. 107; January, 1962.

Continuous Operation of a $\mathrm{CaF_2:Dy^{2+}}$ Optical Maser*

Pulsed optical maser action at 2.36 μ from $\mathrm{CaF_2:Dy^{2+}}$ was recently described by Duncan and Kiss.[1] The emission was ascribed to a transition from a level belonging to the $^5I_6$ manifold to a terminal level, belonging to $^5I_8$, 90 cm^{-1} from the ground state.

In this communication we describe the attainment of continuous maser action in this material and report on some aspects of our investigation related to this operation.

The crystals tested were grown initially as $\mathrm{CaF_2:Dy^{3+}}$ and subsequently irradiated with γ-rays to effect a (partial) reduction of $\mathrm{Dy^{3+}}$ to $\mathrm{Dy^{2+}}$. The crystals tested were prepared with 0.5 per cent, 0.2 per cent, 0.1 per cent, 0.05 per cent and 0.02 per cent of Dy.

The maser resonators prepared from these crystals all had pulse thresholds of 20 to 22 joules. The threshold was measured with the resonator at the center of a helical FT524 xenon flash lamp with a pulse duration of ~0.5 msec.

Since it was found by selective excitation that the useful absorption was concentrated mostly in the 0.8 μ to 1.0 μ region we chose as the pump source for continuous operation a xenon compact arc lamp in which a large fraction of the output is concentrated in this wavelength region.

The experimental setup for continuous operation was described previously.[2] It consists of a highly reflecting elliptical cylinder containing the crystal along one focal axis and the pumping lamp along the other axis. The crystal was mounted in a double dewar, so that it could be bathed by a flowing coolant and surrounded by an annular flow of liquid filter. We also employed another dewar in which the cooling was provided by immersion.

Using a Hannovia 914C1 xenon compact arc lamp which can be run on either ac or dc power the following results were obtained:

	ac Threshold	dc Threshold
0.5 per cent $\mathrm{CaF_2:Dy}$	>800 watts	>800 watts
0.2 per cent $\mathrm{CaF_2:Dy}$	600 watts	660 watts
0.1 per cent $\mathrm{CaF_2:Dy}$	300 watts	350 watts
0.05 per cent $\mathrm{CaF_2:Dy}$	180 watts	210 watts
0.02 per cent $\mathrm{CaF_2:Dy}$	80 watts	100 watts

Even lower concentrations of Dy are being tried.

The power output at 2.36 μ was measured with a PbS photoconductive detector calibrated with the aid of a tungsten ribbon filament lamp calibrated by the National Bureau of Standards. The maximum power output was obtained from the crystal with 0.05 per cent concentration of Dy with a highly transmissive silvered end mirror. A power output of 0.3 watt was measured with 800 watts input to the lamp. Considerable increases in the power output are expected with better quality crystals and from the use of multilayer dielectric mirrors of optimum transmission.

Continuous operation was obtained with either immersion cooling in liquid nitrogen (77°K) or with a minimal flow (<1 cm/sec) of liquid oxygen subcooled to 77°K. Most of the measurements were taken with the flowing oxygen since the reduced bubbling[2] minimized the fluctuations in the power output.

To prevent a conversion of $\mathrm{Dy^{2+}}$ to $\mathrm{Dy^{3+}}$ (which manifested itself in loss of the green tint and return to transparency) we eliminated the pumping radiation at $\lambda < 0.54\ \mu$ with the use of a dilute (7 grams per liter) solution of $\mathrm{K_2Cr_2O_7}$ made to flow in the outer annular space of the dewar. Continuous runs of up to 30 minutes were maintained with no adverse effects. Removal of the filter resulted in bleaching after ~10 minutes.

Fig. 1 shows a portion of a semicontinuous run in which the light source is a GE AH6 mercury lamp fed on ac power (the use of the Hg lamp yielded results similar to the Xe lamp except that the threshold values were larger by approximately a factor of two) and the crystal is the 0.1 per cent Dy. The input power is 800 watts which is ~14 per cent above the threshold value of 700 watts. The upper trace (sweep rate = 5 msec per division) shows the sharp maser spikes, as detected by a PbS detector, riding atop the very low amplitude (~0.2 divisions) fluorescence excursions. The lower trace shows the light output from the pump lamp.

To obtain continuous operation we switched the lamp from ac to dc power. Continuous operation was obtained with less than 600 watts input to the lamp (the reason for the dc threshold being lower than the ac threshold is the long radiative lifetime which is longer than 1 msec) and is shown in Fig. 2. The detector is the same as in the ac case. The upper trace is the de-

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* Received May 17, 1962; revised manuscript received June 4, 1962.

[1] R. C. Duncan and Z. J. Kiss, Meeting of the American Physical Society, Washington, D. C.; April, 1962. (Post deadline paper.)

[2] G. D. Boyd, R. J. Collins, S. P. S. Porto, A. Yariv and W. A. Hargreaves, "Excitation, relation and continuous maser action at 2.613 μ in $\mathrm{CaF_2:U^{3+}}$," *Phys. Rev. Lett.*, vol. 8, pp. 269–272; April, 1962.

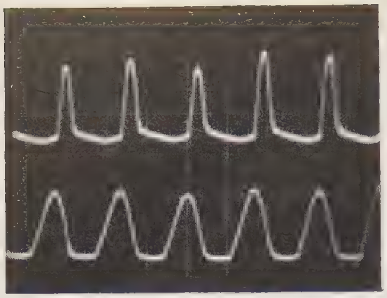

Fig. 1—Semicontinuous run. Upper trace: Maser output with 800 watts input to AH6 lamp as detected by a PbS detector. Lower trace: The pumping light output from the AH6 lamp. Sweep rate (for both traces) =5 msec per division.

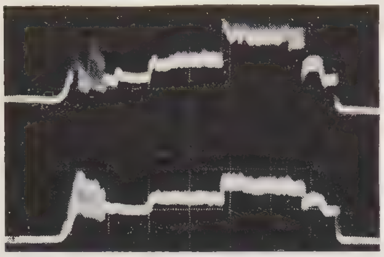

Fig. 2—Continuous (dc) run. Upper trace: Maser output. Lower trace: Pumping light from the AH6 lamp (sweep rate 5 sec per division).

tected 2.36 μ radiation, while the lower one is proportional to the output voltage of the phototube monitoring the pump light. The sweep rate is 5 seconds per division. The input power is varied in steps and ranges from a minimum of 900 watts to a maximum of 1700 watts. The amplitude fluctuations present in the third division are due to the nonstabilized dc power used during this interval. A feedback system, stabilizing the power input to the lamp, turned on at the end of the third division causes a marked decrease in the fluctuations of the pumping light and the maser output. The relaxation oscillation present in the pulsed operation was observed to decay in approximately 3 msec after the onset of oscillation.

In closing it may be of interest to note that the output frequency at 2.36 μ is not absorbed by water vapor,[3] which is the main cause of absorption in the atmosphere.

The author is grateful to Dr. L. F. Johnson for communicating the results of his liquid hydrogen operation while this experiment was in progress, to Dr. C. F. Hempstead for collaborating in the design of the light stabilization scheme, to H. J. Guggenheim who suggested the possibility of γ-ray reduction and who carried out the irradiation, to A. E. Albert for crystal preparation, and to D. H. Olson for expert experimental assistance in all the phases of this investigation. The suggestion for using thin mirrors for increased power output came from Dr. G. D. Boyd. The crystals were obtained from W. A. Hargreaves of Optovac, Inc.

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Murray Hill, N. J.

[3] A. S. Locke, "Guidance," D. Van Nostrand Co., Inc., New York, N. Y.; 1955.

A Proposed Test of the Constancy of the Velocity of Light*

Rapier's proposal[1] for determining absolute motion by seeking a variation in the one-way velocity of light with two synchronized clocks has been thoroughly analyzed by Ives.[2] Ives showed that classical theory (the Fitzgerald-Lorentz contraction theory which is based on an ether) predicts a null result for the experiment. This agrees with the relativistic prediction but contradicts Rapier's classical prediction. The reason for the null result involves the process of synchronizing the clocks. The complete theory is too extensive to be treated here, and the original paper should be referred to for full details. However, the first-order approximation below suffices to explain why Rapier's positive effect is canceled.

Clocks at A and B a distance s apart (Fig. 1) are assumed to have a common absolute motion v in space, which is equivalent to motion through an ether in classical theory. Both clocks are initially positioned at A and the two clocks are synchronized. One clock is then transported to B. In order to accomplish the experiment, the move must occur in a finite time, hence must require a finite velocity. Let this transportation velocity be a constant value w. The time to transport the moved clock to B would be measured by the clock at A by interval

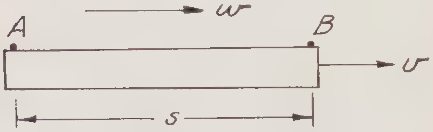

Fig. 1—Synchronized clocks moving in an ether.

$$T_a = T_0(1 - v^2/c^2)^{1/2}, \tag{1}$$

where T_0 is the interval that would be measured by a clock stationary in the ether. The corresponding interval measured by the clock at B while it is being moved is

$$T_b = T_0[1 - (v + w)^2/c^2]^{1/2}. \tag{2}$$

The moved clock records a shorter interval while being transported, but assumes the same clock rate as A once it arrives at B. The difference in clock readings at B with respect to clock readings at A is then, to a first order,

$$\Delta T = T_a - T_b \cong T_0 vw/c^2 \cong sv/c^2, \tag{3}$$

since $T_0 \cong s/w$. This is the amount clock B is set back with respect to clock A. The same result is obtained if a third clock is used to synchronize two clocks initially at A and B. The process of synchronizing two spaced clocks thus results in at least a first-order difference in clock settings which is independent of the velocity used to obtain the spaced synchronization.

The interval t_1 required for a light beam to travel from A to B as measured by the difference in the times t_{a1} and t_{b1} recorded when the light beam passes each clock is

$$t_1 = t_{b1} - t_{a1} = s/(c - v) - \Delta T, \tag{4}$$

since the velocity of the light beam relative to the clocks is $c-v$. Similarly, for a light beam traveling from B to A,

$$t_2 = t_{a2} - t_{b2} = s/(c + v) + \Delta T. \tag{5}$$

The first-order difference between the two travel-times is zero:

$$\begin{aligned} t_2 - t_1 &= \frac{s}{c+v} + \Delta T - \left(\frac{s}{c-v} - \Delta T\right) \\ &\cong 2\Delta T - \frac{2sv}{c^2} = 0. \end{aligned} \tag{6}$$

Ives obtained the same null result with an exact analysis. The proposed experiment, although it should be performed, cannot be be used to detect absolute motion in Newtonian space-time.

If, in addition to the common motion in an ether, one of the clocks, say B, is rotating around A in a circular orbit with a tangential velocity u, a first-order periodic variation in phase results in the reception of a light signal transmitted from one to the other. This periodic phase shift, which is due to the constant change in the angle between u and v, produces a periodic frequency shift. I have previously proposed terrestrial and extraterrestrial tests[3] using this effect to seek a variation in the one-way velocity of light. It should be pointed out that this effect is canceled for a similar reason that there is a cancellation in the nonrotating case above.

The frequency of the clock at A is $f_0(1-v^2/c^2)^{1/2}$, where f_0 is its frequency when stationary in the ether. For the rotating clock at B, its velocity in the ether is $\vec{u}+^{\rightarrow}$ and its corresponding frequency is $f_0(1-(u^2+v^2-2uv \sin \gamma))^{1/2}$, where γ is the angle between s and v. The relative difference in clock frequency for a measurement of a light signal traveling from B to A is, to a first-order,

$$\frac{\Delta f}{f_a} = \frac{f_a - f_b}{f_a} \cong -\frac{uv \sin \gamma}{c^2} = -\frac{\omega sv \sin \gamma}{c^2}, \tag{7}$$

where ω is the angular velocity of the rotating clock. This frequency shift cancels the first-order frequency shift previously found to arise from the angular component of the phase shift due to propagation. For a noncircular orbit, there is also a cancellation of the radial component of the propagation phase shift because of phase shift in the synchronization of the clocks as exemplified by (1)–(6). A null result is predicted in agreement with the relativistic prediction.

It should be noted that the above result

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* Received October 30, 1961.

[1] P. M. Rapier, "A proposed test of the constancy of the velocity of light," PROC. IRE (*Correspondance*), vol. 49, p. 1322; August, 1961.

[2] H. E. Ives, "The measurement of the velocity of light by signals sent in one direction," *J. Opt. Soc. Am.*, vol. 38, pp. 879–884; October, 1948.

[3] M. Ruderfer, "Relativity: blessing or blindfold?" PROC. IRE (*Correspondence*), vol. 48, pp. 1661–1662; September, 1960. *Ibid.*, vol. 49, pp. 630–631; March 1961. "First-order terrestrial ether drift experiment using the Mössbauer radiation," *Phys. Rev. Lett.*, vol. 5, pp. 191–192; September 1, 1960.

for the rotating case is not exact. A complete solution, which has never been presented, involves considerations of acceleration due to the rotation. Furthermore, the use of a gravitational clock, such as the eclipses of a satellite by a planet, for the rotating clock at B has not been fully explored. Frequency variation with motion should apply to all types of clocks. I have suggested elsewhere[4] that the variations of mass and propagation velocity of gravity with motion in an ether must be taken into account in the contraction theory of gravitational clocks. However, in view of the past equivalence of the relativity and contraction theories, it would be surprising if this did not result in the proper frequency variation to give a null effect for an ether drift.

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Author's Comment[5]

My proposal,[1] which has also been made independently by Palacios,[6] is based upon a valid difference between the Newtonian and the Einstein predictions. Some of Ruderfer's proposals, too, are based upon this difference; others, as we have already shown,[7] are not. If, as Ruderfer has indicated, he now wishes to revise his concepts of space and time, and to introduce the irrelevant and untenable hypotheses of Herbert Ives,[2] he is welcome to do so; however, his change of heart cannot affect the laws of physics in any way, nor can it alter the outcome of these tests, which can only be known by experiments conducted to reveal the truth.

There are those who fear the truth, for fear of those whom it may offend, and who fear the experimental ways of finding it. Instead of seeking it, they seek new methods for avoiding it. A favorite device of these is to proclaim that a proposed test will yield null results. Another is to throw up a smoke screen.

The smoke screen used here by Ruderfer is to say that Ives' ether is "classical" and Newtonian. It is neither; it belongs to the space-time continuum of Minkowski and is incompatible with Newtonian space and time. Quite obviously, Ives' ether would have to be alive to behave in the intelligent fashion that Ives expected of it, and most certainly, it must not be confused with the strictly inanimate ether of Newton, whose physical properties the Newtonian Science Foundation is only now developing.[7]

The asymmetrical views of Ives,[2] Sherwin,[8] and others radical were, of course, thoroughly considered in the referenced literature going with our proposal,[1] which papers, apparently, have not been read. It seems, therefore, that the simplest way to refute Ruderfer's arguments is to invalidate his equation (1) which asserts that time flows differently in different systems.

We shall, therefore, impeach the relativists with their own testimony by presenting for the first time the true data from Ives' experiments, and the true meaning of some other experiments,[8] all of which have been misrepresented by the relativists in a sophistic effort to conceal the truth.

Presented in Table I are the original data of the Ives-Stilwell experiments. In the tabulation λ_+ is the observed wavelength of receding hydrogen ions, while λ_- is the wavelength of the same ions, observed as approaching by means of a mirror. From these two Doppler effects alone, one must ascertain the mechanical rate of vibration of the atoms that have generated the wave, and must find out whether this rate, which can serve as a standard for regulating a good time-keeping mechanism, or clock, depends in any way upon the velocity and the acceleration of the ions. The geometric mean wavelength from the two Doppler effects of the moving ions is represented by λ_m, and turns out to be of a value, 4861.3270 Å, that is entirely independent of the velocity of the ions. Such an independent quantity is known as an invariant. Now in mathematical physics, only those quantities that possess this property of invariance have an objective significance; *e.g.*, they can be directly identified with the real properties of real bodies. Thus, it is immediately possible to identify the geometric mean frequency from the two Doppler effects with the mechanical rate of vibration of the moving atoms. Hence, the geometric mean frequency is equal to the mechanical rate of vibration of the atoms, and turns out to be independent of their velocity.

TABLE I

TABULATED DATA OF THE MOVING SYSTEM FROM THE IVES-STILWELL EXPERIMENTS

Plate No.	Voltage	Line	Doppler Effects Due to Receding Atoms λ_+	Doppler Effects Due to Approaching Atoms λ_-	Geometric Mean Wavelength λ_m	Mean Deviation $\lambda_m - \lambda_0$
160	7780	H_2	4875.3655	4847.3255	4861.3253	−0.0017
163	9187	H_2	4876.7495	4845.9495	4861.3251	−0.0019
165	11566	H_3	4875.4175	4847.2775	4861.3271	+0.0001
169	6788	H_3	4871 6880	4850.9880	4861.3270	0.0000
170	10574	H_2	4877.8440	4844.8640	4861.3260	−0.0010
172	13560	H_3	4876.4885	4846.2085	4861.3249	−0.0021
172	13560	H_2	4880.0315	4842.6915	4861.3256	−0.0014
177	18350	H_2	4882.7440	4840.0040	4861.3270	0.0000
214	26735	H_2	4887.2140	4835.5740	4861.3254	−0.0016
214	26735	H_3	4882.4520	4840.2920	4861.3263	−0.0007
215	27270	H_2	4887.4445	4835.3445	4861.3247	−0.0023
216	28185	H_2	4887.9370	4834.8770	4861.3346	+0.0076
218	28185	H_2	4887.9625	4834.8425	4861.3299	+0.0029
222	34395	H_2	4890.8170	4832.0170	4861.3281	+0.0011
223	40190	H_2	4893.3565	4829.4965	4861.3216	−0.0054
228	41640	H_2	4893.4515	4829.4315	4861.3361	+0.0091
230	41640	H_2	4893.9400	4828.9400	4861.3313	+0.0043
231	42280	H_2	4893.7315	4829.1515	4861.3342	+0.0072

Note: The H_β line of the Balmer series was observed throughout the experiment as being 4861.3270 Å for stationary atoms λ_0.

As an additional feature of the experiment, spectral lines for hydrogen ions that were stationary with respect to the laboratory frame were photographed. These ions, which hovered around the filament of the canal-ray tube used by Ives, were unaccelerated during the course of the experiment. Their wavelength was measured as being 4861.3270 Å, which is exactly the same as the mean wavelength of the moving ions that had been accelerated.

The Ives-Stilwell experiments, therefore, have demonstrated with exotic precision that the time-keeping properties of atoms are independent both of acceleration and of velocity; in other words, *their rate of vibration is an invariant under the unrestricted transformation of coordinates.*

Unquestionably then, an atomic oscillator is a suitable standard for driving a clock mechanism that will keep good Newtonian time under any conditions, a time which flows the same everywhere, "evenly and equably, and independent of everything external." The Ives-Stilwell experiments gave precisely null results for the expected time dilatation under various relativistic hypotheses, and thus, have completely invalidated Ruderfer's equation (1).

Similar recent experiments, employing the Mössbauer radiation,[8] have measured resonant wavelengths for moving atoms with extreme accuracy and have confirmed unequivocally the Doppler equations that we had previously derived[9] from the Ives-Stilwell results, *viz:*

$$f = F \Big/ \left(\frac{1}{\alpha} - \frac{V}{c} \operatorname{Cos} \phi \right), \tag{A}$$

for a relatively moving source, and

$$f = F \left(\frac{1}{\alpha} - \frac{V}{c} \operatorname{Cos} \phi \right), \tag{B}$$

for a relatively moving receiver, where F is the true rate of vibration of the atoms, V is the actual relative velocity existing between the atoms and the laboratory, and ϕ is the angle that the ray of light makes with the line of relative motion in the laboratory frame of reference. α is the index of refraction of the relative space, and as we have previously shown,[7] equals $(1+V^2/c^2)^{-1/2}$. Since these are tensor equations, they provide a unique correspondence between f, which is a pure Doppler effect, and whatever values of F, V, and ϕ are selected. For example, in the equations, unlike in the conflicting relativistic forms that have elsewhere been proposed, V can range from 0 to ∞ without involving any imaginary solutions that have to be "explained away," and behaves in every respect like a true time rate of change of distance, inasmuch as it possesses no theoretical limit.

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[4] M. Ruderfer, "The existence of periodic variations in the observations of Jovian eclipses," 1961 IRE INTERNATIONAL CONVENTION RECORD, pt. 5, pp. 139–146.

[5] Received November 27, 1961.

[6] J. Palacios, "The postulates of a new theory of relativity," *Rev. Real Acad. Ci., Madrid*, vol. 54, pp. 313–330; July, 1960.

[7] P. M. Rapier, "An extension of Newtonian relativity to include electromagnetic phenomena," PROC. IRE, vol. 49, pp. 1691–1692; November, 1961.

[8] C. W. Sherwin, "Some recent experimental tests of the clock paradox," *Phys. Rev.*, vol. 120, pp. 17–21; October 1, 1960.

[9] P. M. Rapier, "Resolution of the Clock Paradox of Relativity, II," A.D.I. Doc. No. 6014, 1959 ($1.25 ea.); "A New Philosophy in Modern Cosmology," A.D.I. Doc. No. 6144, 1959 ($2.50 ea.); c/o Chief, Photodup. Service, Library of Congress, Washington, D. C.

Now we have shown in the referenced papers for our proposal,[1] and elsewhere[7,10,11] that (1) has absolutely no physical meaning because it is based upon a fictitious time interval T_a and upon a fictitious velocity v: T_a equals $1/f$, which is only a Doppler effect and which has nothing to do with the time-keeping properties of atoms, while v equals $V(1+V^2/c^2)^{-1/2}$ where V, and not v, is the true time rate of change of distance. It seems unnecessary for us to keep repeating this, but apparently, some of the relativists are unable to read. Eq. (1), and for that matter, all the rest of the relativistic equations, are based upon this same fallacy, which should be quite obvious to anyone who has in philosophical matters a competent faculty for thinking.

Now there is really nothing at all mysterious or mystical about the experiments,[8] or about the Galilean transformations that they yield:

$$t' \equiv t, \; x' \equiv x - Vt, \; y' \equiv y, \text{ and } z' \equiv z. \quad \text{(C)}$$

These results are in precise agreement with Newtonian relativity. Clocks and rods simply behave as they should in classical mechanics and remain the same in all frames of reference. But there is something very strange indeed about the relativists' misrepresentation of these experiments,[8] and about the almost lifelike antics of their so-called clocks and rods, which behave just as though they were in a Walt Disney animated cartoon feature. And there is something stranger yet in Ruderfer's sudden leap, without looking, into the ranks of the PGMSJ (Professional Group of Mathematical Symbol Jugglers).

As is well known, the PGMSJ is composed of indifferent mathematicians who only believe in symbols and whose only apparent mission in life is to misinterpret them. A subgroup, which Ruderfer has apparently joined [since he pretends that (1) is valid], is doing a balancing act on an an escalator, while juggling their mathematical symbols wildly to the accompaniment of Professor Dingle's tune, entitled, "Age Will Hide From Me, if I Vibrate Rapidly." They are also proclaiming solemnly and soberly that they are gods: they can remain young at will and attain virtual immortality simply by traveling fast enough and staying within gravitational fields.[12]

The PGMSJ are open-minded enough to admit that (1) has two real roots, since it is quadratic; *viz.*

$$T_a = \pm T_0(1 - v^2/c^2)^{1/2}, \quad (1)$$

and that both roots can have an equal claim to validity under the postulates of relativity. One is entitled to select the negative root, which states that a reference frame is possible such that a clock at A runs backwards with respect to a clock at rest in Ives' ether. In the words of Palacios,[13] "Dead people would be seen to revive and live backwards until they became babies. Now Einstein was very careful not to enter into conflict with the principle of causality, but it follows from his theory that we can create an accelerated frame in which effects will precede their causes."

As a member of the PGMSJ, Ruderfer must learn to respect their rules and regulations. Therefore, he cannot substitute a Galilean transformation, which is valid only in Newtonian space and time, into a Lorentz transformation, which is valid only in Minkowskian space-time, as he has done with (2). This incompatible formulation leads directly to the spurious first-order asymmetries shown. The correct mathematics for this under PGMSJ rules is to represent the absolute velocity of the clock being transported to B by the symbol u; *viz.*,

$$u = (v + w)/(1 + vw/c^2), \quad \text{(D)}$$

so that (2) becomes

$$T_b = T_0(1 - u^2/c^2)^{1/2}, \quad \text{(E)}$$

and the first-order effect expected by Ruderfer vanishes.

P. M. Rapier
Newtonian Science Found.
Richmond, Calif.

Additional Comment by Ruderfer[14]

Eqs. (D) and (E) are incorrectly applied by Rapier. Although the relativity and contraction theories give the Lorentz contraction factor $(1-\text{velocity}^2/c^2)^{1/2}$ in the same mathematical form, there is a fundamental difference in the interpretation of the velocity used therein. In relativity theory, this velocity is *always relative* and never absolute; in the contraction theory, this velocity is *always absolute* and never relative. The two conventions turn out to represent equivalent interpretations,[15] but the convention adopted must be strictly adhered to; it is improper to mix the two as Rapier has done in obtaining (E). The proper convention in the contraction theory is to refer all velocities to a common reference: the light-transmitting ether. Contrary to Rapier's assertions, this convention preserves the absolute space and time of Newton and justifies the description of the contraction theory as classical. Velocities are added vectorally as in prerelativity physics. This is clearly set forth by Ives.[2] The time-keeping properties of the moved clock are, in the contraction theory, correctly given by (2).

Ives merely extended the previous works and ideas of Fitzgerald, Lorentz and Larmor, and did not introduce "irrelevant and untenable hypotheses," as stated. Eq. (1) derives directly from the Lorentz contraction factor[16] and has been experimentally confirmed by the measurement of the variation of clock rate with relative motion in the Ives-Stilwell experiment.[17] (In fact, this variation can be seen in Table I for a particular line from the variation of the frequency of receding or approaching atoms as a function of voltage.) To deny the propriety of (1) is to deny the validity of the Lorentz transformations.

The final arbitrator in such matters is experiment. If, in accordance with Rapier's view, (2), hence (3) and (7), are incorrect, then a positive effect should be obtained in his[1] and my[3,18] proposed experiments. Some preliminary data bearing on this problem are available from the rotating-disk Mössbauer experiment performed at Harwell.[19] This experiment applies to the one-way terrestrial Mössbauer experiment I proposed provided the frequency shift is recorded as the earth's orientation in space changes. Although this was not done in the original experiment, the maximum frequency-shift variation obtained provides an upper limit for an ether drift. The Harwell group has estimated[20] an upper limit to an ether drift of 100 m/sec ($\Delta f/f < 10^{-13}$, $s=5$ cm, $\omega = 2\pi 500$ rad/sec and $\sin\theta = \sin\gamma = 1$). This is over 4 orders of magnitude less than the minimum positive effect anticipated by Rapier. Note that the nonrotating case is a special case of the rotating case, hence the result applies to both.

M. Ruderfer

Additional Comments by Rapier[21]

I shall leave the PGMSJ to decide by their customary procedure of a majority vote which, if either, of the two irreconcilable interpretations of the mathematical symbol v, offered by Ruderfer, they prefer. The Lorentz-Larmor hypotheses, upon which contraction theory is based, are false and contradictory to Newton's four rules of philosophical reasoning. As a result, the

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[10] J. Palacios, "Reappraisal of the principle of relativity," *Rev. Real Acad. Ci., Madrid*, vol. 55, pp. 3–14; April, 1961.

[11] H. Dingle, "Interpretation of the special theory of relativity," *Bull. Inst. Phys.*, pp. 314–316; December, 1958.

[12] H. Dingle, "An improved method of youth preservation?" *New Scientist*, no. 249, pp. 455–457; August 24, 1961.

[13] J. Palacios, "The clock paradox and the possibility of a new theory of relativity," *Rev. Real Acad. Ci., Madrid*, vol. 53, pp. 511–525; July, 1959.

[14] Received December 27, 1961.

[15] M. Ruderfer, "Re-evaluation of the existence of an ether," PROC. IRE (*Correspondence*), vol. 50, pp. 325–326; March, 1962.

[16] H. E. Ives, "Light signals on moving bodies as measured by transported rods and clocks," *J. Opt. Soc. Am.*, vol. 27, pp. 263–273; July, 1937.

[17] H. E. Ives and G. R. Stilwell, "An experimental study of the rate of a moving atomic clock," *J. Opt. Soc. Am.*, vol. 28, pp. 215–226, July, 1938; vol. 31, pp. 369–374, May, 1941.

[18] See also the erratum in *Phys. Rev. Lett.*, vol. 7, p. 361; November 1, 1961.

[19] H. J. Hay, J. P. Schiffer, T. E. Cranshaw, and P. A. Egelstaff, "Measurement of the red shift in an accelerated system using the Mössbauer effect in Fe^{57}," *Phys. Rev. Lett.*, vol. 4, pp. 165–166; February 15, 1960.

[20] T. E. Cranshaw, private communication, July 8, 1960.

[21] Received March 15, 1962.

Lorentz equations, including (1), cannot be applied to any natural phenomenon at all without causing a contradiction somewhere else in Nature. For example, if in accordance with (1), the Doppler-shifted *wavelengths* actually measured by Ives' diffraction grating,[17] and shown in Table I are presumed by some wild stretch of the imagination to be equivalent to clock settings, then column 4 would be the rate of a receding atomic "clock," while column 5 would simply be the rate of a mirror image of the same clock. The hands of this "clock" would then have to run simultaneously at two different speeds, a slow speed for the directly observed image, and a fast one for its reflection. This is absurd, as it contradicts the law of reflection.

The basic requirement of any kind of time dilation theory whatsoever is that the mechanical rate of vibration of a moving oscillator must differ as a function of velocity from the rate of a similar oscillator at rest in the observer's frame. Clearly, in Ives' experiment, such a difference was not observed. Instead, the rate of the moving oscillator turned out to be independent of its velocity and to be identically equal to the rate of a similar stationary oscillator (by comparison of column 6 with λ_0). This verifies the Galilean kinematics and invalidates all theories requiring time dilation, along with the Lorentz equations, a fact that the PGMSJ has been trying to conceal for over 20 years!

Also verified is the general co-variance of the metric tensor under the Newtonian relativity, as shown by my recent paper.[7] This paper[7] predicts precisely null results for Ruderfer's rotating disk experiment, and so I wish to thank Ruderfer for revealing that this unique prediction of the Newtonian relativity has now been tentatively verified at Harwell.[20]

While there are now many other sets of data confirming the Newtonian relativity, I shall mention only three: 1) If the Lorentz contraction were real, then the Wood, Tomlinson, Essen[22] experiment would surely have revealed it; yet this experiment yielded precisely null results. 2) Neither relativity nor contraction theory satisfactorily explains the combined results of the Sagnac experiments and of Fizeau's tests with moving liquids. Only Newtonian relativity[7] gives a simple and consistent explanation for both. 3) The meson lifetime data cited by Sherwin,[8] when truthfully interpreted, demonstrate unequivocally that the flow of time is independent both of velocity and of acceleration. For example, when the measured mean path of 9.4 km for the flight of decaying 1.3 Bev cosmic-ray muons is divided by their known velocity at this energy of 3.7×10^6 km/sec, a mean lifetime in flight of 2.5 μsec is obtained,[9] which is the same, within the limits of experimental error as the measured lifetime of stationary muons in the laboratory frame (2.15 μsec). These clearly invalidate the basis for Ives' so-called analysis.[2] Such concepts cannot be used to predict the outcome of my proposed test.[1]

P. M. Rapier

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[22] A. B. Wood, G. A. Tomlinson, and L. Essen, "Effect of the Fitzgerald-Lorentz contraction on the frequency of longitudinal vibration of a rod," *Proc. Roy. Soc.*, vol. 158, pp. 606–633; February 3; 1937.

Project Luna See*

In order to determine some of the possibilities of optical maser radar we conducted experiments with the Moon as a target.

Predicted Performance

The basic system was conceived as consisting of a pulsed transmitter and a receiver. The transmitter was to be a ruby maser, radiating at 6934Å, and focused by a 12-inch reflecting telescope. The receiver was to be a photomultiplier tube illuminated by light collected in a 48-inch reflecting telescope. The photomultiplier output was to be displayed on a suitably delayed oscilloscope trace (the A-type radar display).

If the light from the ruby were perfectly coherent over the cross section, and illuminated the 12-inch telescope uniformly, the beam divergence, given by λ/D, would be about 2×10^{-6} radians. Even allowing for a beam width 100 times greater, the resulting spot on the Moon, at a range of 200,000 miles, would constitute a point source for re-radiation to the Earth. Thus, if we assume the reflected light to obey Lambert's law, we get a modified "radar" equation, in which the received light energy W_R at the photocell varies as R^{-2} instead of R^{-4}.

$$W_R = W_T \frac{A\rho}{\pi R^2} K_a{}^2 K_T K_R$$

where A is the area of the receiving aperture, R is the distance to the Moon, W_T is the energy of the transmitted pulse, K_a is the transmission through the atmosphere, K_T and K_R are the optical efficiencies of the receiving and transmitting system respectively, ρ is the normal albedo of the lunar surface. We estimated (or knew) the constants of our system to have the following values: $A = 1$ m², $K_T = 0.75$, $K_R = 0.37$, $K_a = 0.85$, $\rho = 0.15$ (for a bright spot on the Moon), $R = 384{,}000$ Km, and thus $W_R/W_T \approx 6.5 \times 10^{-20}$. If $W_T = 50$ joules at $\lambda = 6934$ Å, there would be about 12 5 photons incident on the detecting photosurface per pulse.

Competing with our own signal are three noise sources: the dark current emitted by the photosurface, the ambient light from the lunar surface, and light scattered in the atmosphere and the telescope. Manufacturer's data indicated dark currents for a cooled photomultiplier corresponding to about 10 photoelectrons/sec. Since the maser pulse is about $\frac{1}{2} \times 10^{-3}$ sec in duration, the expected, received photon flux is of the order of 2.5×10^4 photons/sec. At 6900 Å the efficiency of the photo surface is about 3 per cent, so that the expected signal component is about 750 photo electrons/sec. Thus, the dark-current noise was expected to be negligible. At night, and aiming at the dark side of the Moon, the principal interfering sources are the Earth-light and the scattered light of the crescent. The new Moon appears in the sky too early in the daytime, with a consequent high level of scattered light in the atmosphere. In addition the earthshine on the dark portion of the Moon is maximum at new Moon. Near full Moon, the dark portion of the Moon is darkest, but the large amount of light scattered from the sunlit surface would make operation very difficult. The brightness of the dark side of the Moon varies by about a factor of 15 from just after new Moon to shortly before full Moon (a variation of 100° in phase).[1] From published data[2] it is estimated that the power density in the visible range, incident on the Earth, reflected from the dark side of the Moon at first quarter, is $S = 3.3 \times 10^{-15}$ watts/m² $\times$(km² of Moon area). In a bandwidth of 7 Å, centered at 6934 Å, this corresponds to a power density of about 0.7×10^{-17} watts/m²km², or about 28 photons/sec (meter)² (kilometer)². Existing estimates of scattered light indicate an intensity 1 to 10 times greater than the above number.

The field of view of the receiving system was assumed to be limited by an aperture to an area on the Moon of about 5000 km². Thus the background signal received by our 1 m² telescope was expected to be about 1.4×10^5 photons/sec due to Earth light, plus a component up to 10 times greater due to scattered light. Assuming 5×10^5 photons/sec, and then including K_R and K_a, we find a "noise" flux of 160,000 photons/sec incident on the photocell. The maser pulse duration is about $\frac{1}{2} \times 10^{-3}$ sec, and thus the expected background photon flux per pulse length would be about 80, and might be as low as 30.

These numbers indicate that the signal-to-noise ratio to be expected, for the parameters chosen, might be of the order of 0.5 or less.

Description of the Apparatus

The telescope used for transmitting was of a Cassegrainian reflecting type, focal length 4.55 meters, aperture 0.29 meter (12 inch). The maser unit, except for small modifications to the cooling system, is as described by Bowness, Missio and Rogala. (See next communication, this page.) Each of the four flashlamps is connected through a 0.3-mH choke to an 840-μF bank of capacitors, charged to 2200 volts. In laboratory tests the output of the maser, as measured with a calorimeter, was observed to be about 50 joules. Since the cooling in the telescope installation was improved over that used in the above tests, the actual radiated energy may have been somewhat greater. The maser beam is focused (Fig. 1) by a lens of 102-mm focal length onto the focal plane of the transmitting telescope. Measurements were made of the size of the focused spot by burning holes through an aluminum foil. The resulting holes had a diameter of about 0.9 mm. If the hole size is assumed to indicate the image size, the beamwidth radiated by the telescope is 0.2 mrad, maximum. The receiving telescope (Fig. 2) was also a Cassegrainian reflector of focal length 18.2 m and collecting area of 1.00 m² (48-inch diameter).

A dichroic mirror was used to separate the red part of the spectrum so that the residual green light could be used for viewing through an eyepiece. The red portion of the

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* Received June 4, 1962; revised manuscript received, June 7, 1962. This work was supported in part by the U. S. Army Signal Corps, the Air Force Office of Scientific Research, and the Office of Naval Research.

[1] A. Danjon, "Albedo, color and polarization of the Earth," in "The Solar System," vol. II, G. P. Kuiper, Ed., The University of Chicago Press, Chicago, Ill.; 1954.

[2] M. Minnaert, "Photometry of the Moon," in "The Solar System," vol. III, G. P. Kuiper and B. Middlehurst, Eds., The University of Chicago Press, Chicago, Ill.; 1961.

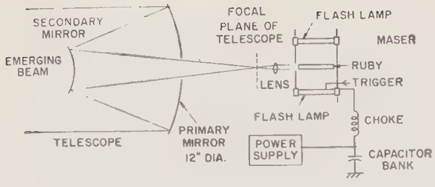

Fig. 1—Simplified diagram of transmitter.

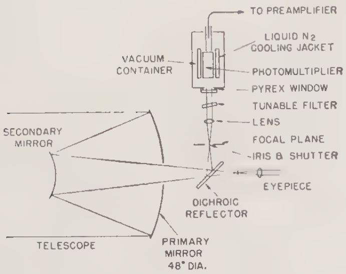

Fig. 2—Simplified diagram of receiver. The interference filter was tuned by rotating its plane with respect to the optical axis of the system.

spectrum passed through a camera shutter and iris assembly at the focal plane, and was then collimated by a lens. The adjustable iris allowed us to modify the field of view accepted by the photomultiplier. Throughout the experiments the diameter of the circular opening of the diaphragm was 3.6 mm, equivalent to a field of view of 0.2 mrad. After the diaphragm and lens the red light passed through a combination of blocking filter and narrow-band tunable interference filter having a bandwidth of 7Å.[3] The filtered light fell on the surface of an EMI 9558-A photomultiplier tube which was cooled to liquid nitrogen temperature. The signals from the photomultiplier were preamplified and then displayed on one trace of a double-beam oscilloscope. On the second trace, timing signals from a Time Mark Generator were displayed. The 20-msec sweep was delayed by about 2.6 seconds, differently on each night according to the distance to the Moon. Each trace was photographed. The distance to the Moon was computed with the aid of Ephemeris data.

In order to obtain accurate synchronization between the maser pulse and the delayed sweep, the firing was initiated by a 1-sec repetition rate trigger pulse, derived from the timer and gated by a push-button circuit. This trigger pulse also activated the delayed oscilloscope sweeps.

Results

The experimental results are summarized in Table I. The experiments are grouped in four series. The number of consecutive flashes in each series is given in column 3. Column 5 gives the average signal level (number of counts) obtained in a $\frac{1}{2}$-msec interval, due to Earth light and scattered light. The average was computed from actual counts in $\frac{1}{2}$-msec intervals at time delays different from the expected round-trip time delay of the signal. Column 6 gives the standard deviation of the background level. The total number of intervals used in establishing the background is given in column 4. Column 7 gives the average photoelectron count obtained in that 0.5-msec interval where echoes were expected, and is therefore a measure of the signal-pulse noise.

It is evident that signal-pulse noise (column 7) exceeds the average noise by a significant amount in all the experiments, but especially in the first and last ones. After completion of the experiments there were no signs of damage to the various optical elements of the transmitter. The focusing lens of the maser showed slight evidence of dust burned into the anti-reflecting coating.

TABLE I

1 Eastern Standard Time	2 Region of the Moon	3 Number of Flashes	4 Number of Intervals	5 Average Noise	6 S.D.	7 Average Count in Expected Interval
May 9, 1962; 21^h56–22^h07	Albategnius 15°S8°E	11	15	1.11	0.28	1.91
May 10, 1962; 21^h52–22^h34	Copernicus 10°N20°W	23	16	1.39	0.22	1.74
May 11, 1962; 21^h57–22^h50	Tycho 43°S10°W	30	22	1.42	0.16	1.83
22^h54–23^h15	Longomontanus 50°S20°W	16	17	1.52	0.19	2.32

We wish to acknowledge the help of J. Daley, Jr. of Lincoln Laboratory in the adjustment and use of the telescope; of G. Hardway and S. Kass of Raytheon Company in the testing and use of the maser; and of G. McGrath of Lincoln Laboratory in computing the Ephemeris data.

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[3] The filter was manufactured by Thin Film Products, Inc., Cambridge, Mass.

A High-Energy Laser Using a Multi-Elliptical Cavity*

The use of a cylindrical cavity of elliptical cross section to enable efficient coupling of a laser flash lamp to a ruby has been suggested by M. Ciftan, *et al.*[1] An improvement upon this technique is the use of multiple cavities having a common focal line. In this way it is possible to couple the light from a number of flash lamps into one ruby rod.

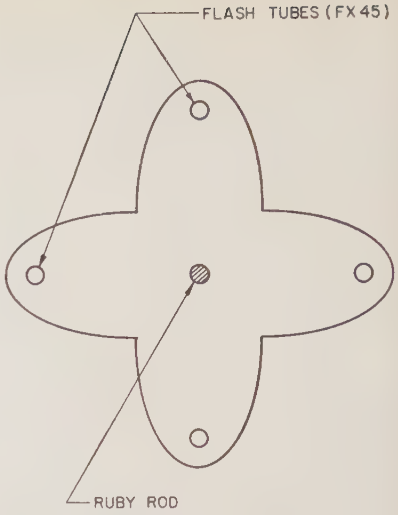

Fig. 1—Cross section of multiple ellipse laser.

A cross section of such a device using four cavities is shown in Fig. 1. Mathematical analysis indicates that, by the correct choice of cavity dimensions, the efficiency of each of the four cavities can be 75 per cent of that of a single ellipse. This loss in efficiency is caused by the removal of the cavity wall in the region about the ruby common to all the ellipses.

It is found that the efficiency of coupling light into the laser crsytal decreases as the number of cavities is increased. A point is reached where the increased pump light available from an extra flash tube is offset by the reduction in efficiency caused by adding the extra cavity.

There are other important considerations. The elliptical cavity is an efficient means of coupling provided the diameter of the plasma column within the flash tube is not greater than the crystal diameter. Also the plasma diameter should be small in comparison with the cross-sectional dimensions of the cavity to prevent aberration of the image formed at the crystal. As the axial ratio of the ellipse is increased, the angular distribution of the light arriving at the crystal becomes less homogeneous. The use of four cavities greatly reduces the last problem.

Choosing the best compromise between the above problems, a four-ellipse laser was built using a 6-inch long cavity. The ratio of minor to major axis was 0.625 and the over-all cross-sectional dimensions of the unit are 16 inches×16 inches.

Measurements were made by placing a heat sensitive paper around the ruby and firing the flash lamps at low energy. The results indicated that light from each of the four cavities was well focused on the ruby while this illumination had reasonably uniform angular distribution.

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* Received June 4, 1962.

[1] M. Ciftan, C. F. Luck, C. G. Shafer and H. Statz, "A ruby laser with an elliptic configuration," Proc. IRE (*Correspondence*), vol. 49, pp. 960–961; May, 1961.

Taking advantage of the excellent low-temperature thermal conductivity of pink ruby it was cooled by clamping both ends in copper heat sinks maintained at liquid nitrogen temperature. In order to keep the efficiency as high as possible, no glass or quartz envelopes are located between the ruby and the flash tube, but dry nitrogen or air is used to cool the flash tubes and prevent the formation of frost.

Six-inch 2,000 joule linear flash tubes (EG and G FX45) were used giving a total input energy of 8000 joules. The duration of the flash is approximately 1 msec while the laser action lasts about half this time. The minimum recycling time is 30 seconds. Using a 6-inch long ⅜-inch diameter ruby having a chromium concentration of 0.04 per cent,[2] the output energy was about 50 joules when measured by a calorimetric technique similar to that described by Koozekanani, *et al.*[3] Experiments are currently being carried out to increase the output. The ruby had flat parallel faces. The back face had a 99-per cent reflecting dielectric coating and the front face was clear. The orientation of the optical axis was 57°.

The authors wish to thank G. Hardway for his assistance during the experimental stages and for performing the measurements of output energy.

C. Bowness
D. Missio
T. Rogala
Raytheon Co.
Waltham, Mass.

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[2] Supplied by R. Meller Co., Providence, R. I.

[3] S. Koozekanani, P. P. Debye, A. Krutchkoff, and M. Ciftan, "Measurements of the laser output," Proc. IRE (*Correspondence*), vol. 50, p. 207, February, 1962.

Experimental Verification of the Price-Radcliffe-Kane Tunneling Equation*

This letter reports experimental data obtained with germanium reverse biased tunnel diodes. A comparison has been made between observed diode characteristics, the early theoretical model of Esaki,[1] and the calculations of Price and Radcliffe[2] followed by Kane.[3]

Esaki pointed out that the qualitative features of the tunnel-diode characteristic are accounted for by considering an energy-conserving tunnel process between filled and unfilled energy states. A further assumption that all energy conserving transitions may occur with equal probability Z leads to the Esaki integral[1] of (1):

$$J = AZ\int_{E_v}^{E_c}[f_c(E) - f_v(E)]\rho_c(E)\rho_v(E)dE \quad (1)$$

where $f_c(E)$ is a Fermi function denoting the probability that a state at energy E in the conduction band is occupied, $\rho_c(E)$ is the density of such states at energy E, E_c is the conduction energy band edge, and A is a constant. The factors with the subscript v have a similar meaning on the p-type junction side. If one assumes a simple spherical energy surface for the valence and conduction bands the Esaki integral takes the form of (2) and for the $T=0$°K case integrates into the explicit form of (3) for reverse bias values,

$$J = A'Z\int_{E_v}^{E_c}[f_c(E) - f_v(E)] \cdot\sqrt{E - E_c}\sqrt{E_v - E}\,dE \quad (2)$$

$$J = \frac{A'Z}{2}\left\{\frac{a\sqrt{E}}{2}(a-E)^{1/2}\left[1+\frac{2}{a}(a-E)\right] + \frac{a^2}{2}\sin^{-1}\sqrt{\frac{E}{a}}\right\}\Bigg]_{\delta_c}^{\delta_c - qV} \quad (3)$$

$$a \equiv \delta_c + \delta_v - qV \qquad qV0$$

where V is the applied voltage bias, and $\delta_{\min}$ is the smaller of the two Fermi level penetrations into the respective energy bands. The tunnel probability Z has been evaluated by Keldysh[4] for individual electron transitions across a region of constant field F in terms of F, the tunnel barrier ϕ_g, and the tunnel mass m^* in (4).

$$Z = \exp\left(\frac{-\pi m^* \phi_g{}^{3/2}}{2q\hbar F}\right). \quad (4)$$

The tunnel probability Z above may be used to multiply the Esaki integral in (2) if desired. Price and Radcliffe[2] and Kane[3] have made calculations for the tunnel current J by performing integrations over both k space and energy. Here the constraints of momentum and energy conservation are used. The transition probability Z is not neglected during the integrations. The solution for the tunnel current J is expressed as (5), where n^* is doping density.

$$J = \frac{q\sqrt{m^*n^*}}{36\pi\hbar^2\sqrt{K}}\exp\left(\frac{-\pi\sqrt{m^*}(E_g - qV)}{2q\hbar\sqrt{n^*}}\right) \cdot\int_{E_v}^{E_c}[f_c(E) - f_v(E)]dE. \quad (5)$$

This equation is referred to as the *PRK* tunnel equation here and results in a relatively simple current-voltage dependence shown in (6) at $T=0$ for V and $E_\perp$ small,

$$J = \alpha V\exp(-\beta V) \quad (6)$$

where α and β are constants given by (7) and (8).

$$\frac{q^3}{18\hbar^2}\sqrt{\frac{m^*n^*}{\pi K}}\exp\left(\frac{-2\beta E_g}{g}\right) \quad (7)$$

$$\beta = \frac{1}{8\hbar}\sqrt{\frac{\pi m^* K}{n^*}} \quad (8)$$

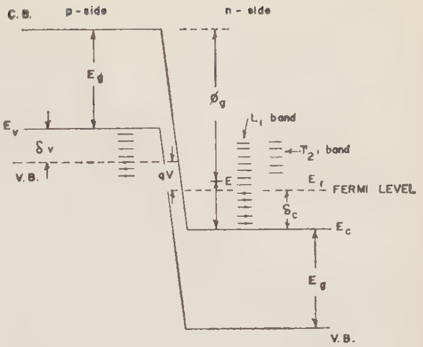

Fig. 1—Energy band alignment for reverse biased tunnel junction indicating the direct and indirect conduction bands.

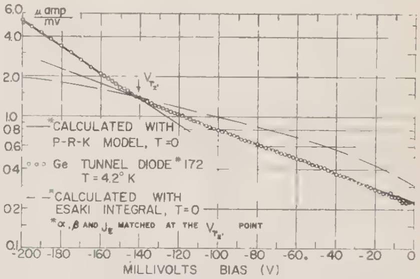

Fig. 2—Comparison of Price-Radcliffe-Kane tunnel equation and the Esaki integral with experiment.

These tunnel calculations are derived for a direct tunnel process between simple energy surfaces such as is expected for tunnel junctions in InSb, GaAs, and slightly degenerate n-type GaSb. In the reverse biased germanium tunnel junction an indirect component in addition to direct tunneling between simple energy surfaces may be observed.[5] Fig. 1 shows that with sufficient reverse bias the valence band becomes aligned with the conduction band (000) energy surface permitting direct transitions. At a bias voltage $V_{\Gamma 2'}$ the tunnel process changes from an indirect process to one in which direct transitions are important. The voltage point $V_{\Gamma 2'}$ is clearly defined by the experimental data plotted in Fig. 2. Here the Esaki integral and the *PRK* tunneling equation are matched to the experimental data at the $V_{\Gamma 2'}$ point. The Esaki integral with or without the tunnel probability Z coefficient gives a poor fit to the experimental characteristic while the *PRK* relation provides an accurate fit to the data in both the indirect and direct tunneling portions of the characteristic out to 200 mv. The tunnel junctions used in this investigation consist of In and In-Ga pellets alloyed to As and P doped wafers.

Discussions with Dr. J. M. Radcliffe, and the assistance of J. Gonsowski and J. Sitarik with the fabrication and testing of units, have been very helpful in this investigation.

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Carnegie Inst. Tech.
Pittsburgh, Pa.

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* Received March 22, 1962. This work was financed in part by Office of Naval Research Contract Nonr 760 (09).

[1] L. Esaki, "A New Phenomenon in narrow germanium p-n junctions," *Phys. Rev.*, vol. 109, p. 603; January, 1958.

[2] P. J. Price and J. M. Radcliffe, "Esaki tunneling," *IBM J. Res. & Dev.*, vol. 3, pp. 364–371; October, 1959.

[3] E. O. Kane "Theory of tunneling," *J. Appl. Phys.*, vol. 32, pp. 83–91; January, 1961.

[4] L. V. Keldysh, "Behavior of non-metallic crystals in strong electric fields," *Soviet Phys. JETP*, vol. 6, pp. 763–770; April, 1958.

[5] J. V. Morgan and E. O. Kane, "Observation of direct tunneling in germanium," *Phys. Rev. Lett.*, vol. 3, pp. 466–468; November, 1959.

Borderline Affairs*

I will be very surprised and disappointed if mine is the only letter that you receive as a result of your reporting the visit of the El Paso Section to Chihuahua, Mexico, in the December, 1961, issue of the PROCEEDINGS.[1] Surely, the IRE has been in existence for too long a time for any Section to claim "firsts" without running a considerable risk of being abruptly corrected.

The Ottawa (Canada) and Syracuse (U.S.A.) Sections have been very closely related for some time past. In April, 1960, the Ottawa and Syracuse Sections held a joint meeting in Syracuse, and in May, 1961, the Syracuse Section came to Ottawa to hold a joint meeting here. These were not just visits for an evening, since the distances involved are too great. Most of the members set off with their wives early on the Friday mornings, visited points of interest in the host cities in the afternoon, and then joined their host Section in the evening for a dinner meeting. A large number stayed in the host city for the weekend. I would not dare to suggest that these exchange visits between a U. S. Section and ours were firsts for fear of having some other Section near your northern border, or some other Section in Region 8, or even my own Section point out earlier examples.

I do, however, congratulate El Paso, even if their idea was not original. We have found, in both Sections, that the exchange visits have aroused a considerable enthusiasm among the members. We hope, this year, to introduce a third section to make the meetings a joint affair between the three Sections on an annual basis. We would, I am sure, welcome the El Paso Section if they wished to come this far for a visit.

R. S. THAIN
Immediate Past Chairman
Ottawa Section
Ottawa, Ontario, Can.

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* Received January 10, 1962.

[1] See p. 1741.

Some Results from the Measurements of the Noise Parameters in Electron Beam*

To analyze the noise behavior of the low-noise traveling-wave tube, the direct measuring method of the noise parameters in longitudinal electron beams has been developed by Saito[1] and measured by Smullin and Zacharias.[2] This note offers other information for this problem.

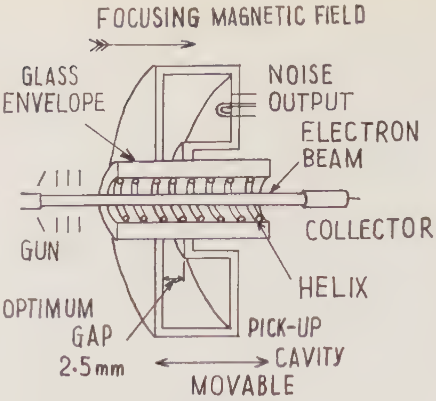

Fig. 1—Cavity set up for measurement.

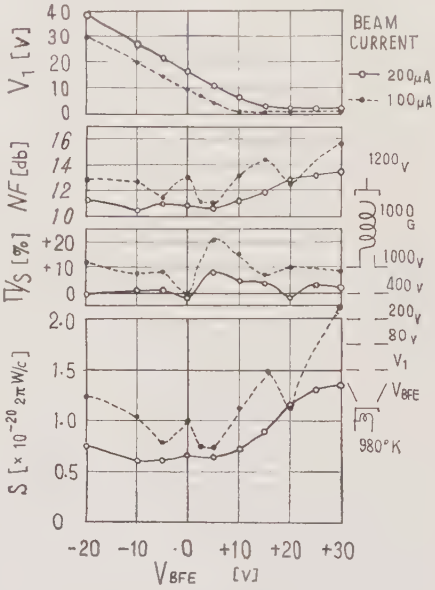

Fig. 2—Beam-forming-electrode voltage vs noise parameters.

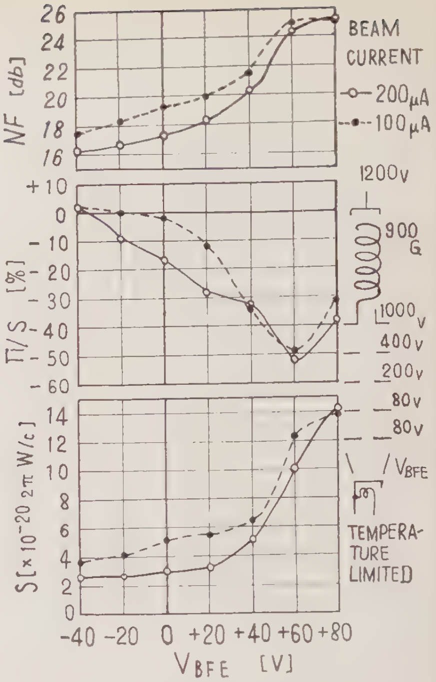

Fig. 3—Beam-forming-electrode voltage vs noise parameters in temperature-limited region.

The noise parameters, S and Π/S, are measured in the 4000-Mc band. A new measuring method is applied to the conventional low-noise tube with the noise pick-up cavities placed on the sealed-off glass envelope (Fig. 1), under the condition that the wave-on helix is completely off-synchronized with the electron beam waves. To avoid the coupling between the helix and cavity, the cavity gap length is determined by the preliminary experiment to be 2.5 mm. The power coupling factors between beam and cavity, between helix and beam, and between helix and cavity are -25 db, -40 db and -20 db, respectively. Therefore, the margin to the undesirable coupling is about -35 db. The diameters of the beam, helix and outer wall of the glass envelope are 1.0, 3.2 and 5.22 mm, respectively. The noise output and the standard noise are chopped by a ferrite switch. The selective beam coupler, devised by Saito,[1] is applied to the two outputs of the cavities in the measurement of the Π/S. The noise output attenuates nearly exponentially by the distance between the beam and the cavity gap and comes down to the order of 0.1° K. Thus, the highly sensitive noise detecting apparatus, such as a parametric preamplifier with approximately 3-db over-all noise figure and 10-Mc bandwidth, and a synchronous detector with the automatic nullifying mechanism by a servomotor-controlled precision attenuator, are needed. The system fluctuation resulting from the receiver noise is 0.1°K. The absolute value of the noisiness is calibrated by the ideal full shot noise when the beam current is reduced down to several microamperes.

The validity of the one-dimensional theory of beam-impedance transformer is certified by changing the second, third and fourth anode voltages, except in such extreme cases as when the anode voltage goes down to zero or becomes negative and affects the beam current.

The beam-forming-electrode (BFE) voltage changes at the constant beam current (Fig. 2). Usually, the parameter S goes up in higher BFE voltage, reduces to the minimum near zero, and increases slightly with negative BFE voltage. Exceptionally low second anode voltage makes the S go up at the negative BFE voltage, *i.e.*, the high first anode voltage. The parameter Π/S is slightly positive in many results.

When the heater power goes down and the cathode comes to the temperature-limited region, the S goes up to 20 db of the equivalent noise figure, and the Π/S goes down to -50 per cent in accordance with the positive BFE voltage. This decrease of the Π/S occurs at the high BFE voltage as in Fig. 3, and no decrease is observed at zero or negative BFE voltage. This decrease of the Π/S might be due to the increase of the effective resistance of the cathode or its interlayer at the positive BFE voltage. The decrease of the Π/S indicates a minimum near 1000 gauss of the focusing magnetic field.

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* Received December 26, 1961; revised manuscript received January 22, 1962. This work is a continuation of that done by the author while at the Massachusetts Institute of Technology, Cambridge, Mass.

[1] S. Saito, "New method of measuring the noise parameters of an electron beam," IRE TRANS. ON ELECTRON DEVICES, vol. ED-5, pp. 264–275; October, 1958.

[2] A. Zacharias and L. D. Smullin, "Noise reduction in electron beams," IRE TRANS. ON ELECTRON DEVICES, vol. ED-7, pp. 172–173; July, 1960.

An interesting example of the decrease of the S is found at the relatively high cathode temperature and at the negative BFE voltage. This decrease amounts to several decibels. The Π/S in this case shows not a little negative value which is affected by the focusing magnetic field.

The probable errors of these measurements are $\pm 0.1\times 10^{-20}\ 2\pi W/c$ in the S and ± 10 per cent in the Π/S. These results suggest that the noise parameter measurement on the sealed-off glass envelope is possible when accompanied by a precise detecting system.

The authors very much appreciate the aid of Profs. L. D. Smullin, H. A. Haus and A. Bers of the Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge. The authors also appreciate helpful discussions by Dr. J. Hamazaki of the Institute of Industrial Science, University of Tokyo.

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"Self-Educating" Pattern-Recognition Schemes

M. L. Minsky*

Clavier[1] criticizes the state of the art in character-recognition machines and proposes a mechanism alleged to have no shortcomings! He criticizes the machines in existence today because ". . . not all possible classifications can be learned and some . . . may necessitate a great number of self-adjustments before they are learned. . . ." He even criticizes the authors for discussing the limitations of their machines—a criticism that the reader of the literature will find quite incredible.

Clavier then proposes, apparently in deadly earnest, an answer to the problem. His machine requires a new and separate memory entry in which to store a *full copy of each instance encountered of each character to be recognized*. If an input pattern differs, at even a single point, from all previously recorded examples it cannot be recognized until a new entry for it is made in a (serially-searched!) tape memory.

This device has no "heuristic connection"[2] to enable it to deal with signals which happen to be somehow similar to, but not exactly the same as, signals it has already learned. That means that it cannot work in the presence of any variety of noise or distortion. And this is precisely the problem faced, and in most cases faced up to, by workers in this field.

The problem is thus one of finding "properties" which are at least partly invariant of the commonly encountered distortions encountered in the practical situation. Some machines have the properties built in at the start; the learning machines have to discover them somehow. The important thing is that each scheme must of necessity make its machine especially good at building up or recognizing some classifications and, also of necessity, especially bad at others. Clavier's complaint that papers in this field contain excessive discussion of such biases and limitations is startling to me because I feel that 1) this is the heart of the matter and the proper subject of the papers and that, 2) in most of the papers the limitations are too often unrecognized or partially concealed.

A most recent example of the need for such a discussion is supplied by the recent note of M-K. Hu,[3] in which it is proposed that one use moment-invariants for pattern-recognition. One can indeed easily find sets of functions, or properties, which are invariant under the commonly encountered transformations of translation and similarity (*e.g.*, by methods like those described in the classic paper of Pitts and McCulloch[4]). But how many invariant moments will one need to describe a pattern for practical purposes? How will they be affected by the common distortions other than the geometric ones they are designed to resist? What about figures with smears, blurs, deletions, runs? One needs invariance for these transformations, too. Without attention to such mundane, practical matters there is really very little to say; merely finding invariants of simplest classical transformation groups is trivial exercise. Indeed, observe the steps used by Hu to achieve invariance. His equation (3) normalizes the figure with respect to its center of gravity. Eq. (6) normalizes it then with respect to area. Eq. (10) then normalizes orientation. This is precisely the process described in my paper.[5] Then Hu remarks that such properties (normalized moments) can distinguish letters. To be sure. The heart of the pattern recognition problem, however, is *not* just to discriminate, but to group heuristically related figures into the same classes: that is, to group together figures that should be treated alike for the actual problem being solved.

To return to Clavier's proposal. Almost all the successful character-recognition devices in the literature have certain common features. With each class to be recognized is associated some device or configuration of parts which calculate a relative score for that class. Each score is based on one or more measurements of the input; it may involve correlation with previously identified or built-up templates, or it may involve more intrinsic relations between parts of the input. In any case the machine identifies an unknown figure on the basis of which class has the highest score.

Now Clavier talks about machines which have memories in which the correspondence between the input patterns and the output classifications are stored, in some sort of one-to-one manner. I cannot recall any proposed character-recognition devices (except Clavier's) for which the term "one-to-one" could be so used in its conventional sense. Since he seems to mean this, his device can have no capacity whatever for generalization or induction. Surely this is no examplar on which to base a broad and public condemnation. But on the contrary, it can serve as an example to encourage other originators of new pattern-recognition schemes to undertake the scientific responsibility of explaining, in their papers, the limitations as well as the virtues of their proposals. We can ask this at least in scientific publication, if not in the public press-releases about the latest cyberknick-knacks.

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and Computation Center
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* Received September 14, 1961.

[1] P. A. Clavier, "Self-educating machines for recognition and classification of patterns," Proc. IRE (Correspondence), vol. 49, p. 1335; August, 1961.

[2] Some of the terms in this letter are defined in M. L. Minsky, "Steps toward artificial intelligence," Proc. IRE, vol. 49, pp. 8–30; January, 1961.

[3] M.-K. Hu, "Pattern recognition by moment invariants," Proc. IRE (Correspondence), vol. 49, p. 1428; September, 1961.

[4] W. Pitts and W. S. McCulloch. "How we know universals," *Bull. Math. Biophys.*, vol. 9, 1947.

[5] Minsky, *op. cit.*, see the last lines on p. 11.

C. N. Pryor[6]

The "Self-educating machine" proposed by Clavier,[1] and his discussion concerning the design philosophy of such machines, omits an essential characteristic of classification devices; that is the ability to generalize input stimulus pattern characteristics. Indeed, the operation of his proposed device requires that every possible input pattern be presented to it during the training session, and the correct output (as determined by some external device) be stored in the machine at a location corresponding to the input pattern. As such, the device is not a learning machine at all, but simply a memorizing machine or a catalog of all possible inputs and their corresponding outputs. As implied by Clavier, the learning machine can then expect to do no better than the device which is supplying it with the correct answers, and so it has no utility whatsoever.

Learning machines have application to problems in which the total number of possible input patterns is too large to warrant direct analysis of each input pattern to determine its desired output, and hence, where the desired outputs have been determined for only a small proportion of the total number of input patterns. An example of this is the letter recognition problem, where the machine is exposed only to reasonably common forms of each letter during training and is required to make an intelligent decision concerning patterns for which it has not been trained.

This amounts to stimulus-generalization, usually in the form of deciding that the input pattern is "nearly like" some other pattern for which the machine has been trained. The output of the machine is then made equal to the output stored for the "most similar" trained input pattern. This process may be visualized as an operation in

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[6] Received October 9, 1961.

a many-dimensional input space in which each point represents an input pattern, and the coordinates of the point in the input space represent (perhaps in a nonlinear fashion) the value of the several inputs to the device. The "most similar" trained pattern is then defined as the trained point physically nearest the point in input space corresponding to the input pattern being tested.

A machine of this sort is capable of learning any possible classification of input patterns, yet for many classifications it is possible to train the machine without exposing it to every possible input pattern. For most practical classification problems, small changes in one or a few of the inputs will usually not change the required classification. This is equivalent to saying that nearby points in the input space will tend to belong to the same class, and the input space can be divided into continuous regions where all the points in a given region belong to the same class. In this case, the entire classification scheme can be learned simply by training the machine on points in the vicinity of the boundaries between regions, rather than having to train it for every possible input pattern. Another useful result of stimulus generalization in the learning machine is its capability to deal with problems in which the proper classification has not been previously established for every possible point. In the character recognition problem it would be an impossible task to assign *a priori* a classification to each possible written form, so only a random sampling of input patterns is available to train the machine. The learning machine will then, through its inherent capabilities, fill in the remaining possible input patterns with the best estimate of the proper classification based on the "most similar" criterion. This capability allows the machine to become a better classifier than its trainer, and thus eliminates the requirement that the device supplying the correct answers must contain the complete classification scheme.

It is possible to build a machine of the sort described above simply by having it search out from the point in input space being interrogated in an expanding hypersphere until a point which has been trained is reached. Then the machine responds with the classification stored for that point. If all the inputs are binary quantities, this amounts to searching all the input patterns which differ in one bit from the one being tested, then those differing in two bits, etc., until one is found for which the classification has been defined. Training is accomplished simply by storing the desired response in the proper location. This can be done without difficulty if the input pattern contains no more than about 15 to 20 bits; however if the input patterns are much more complicated than this, the searching problem becomes unwieldy if it is done explicitly. Here it is necessary to develop some other machine organization which implicitly determines the closest trained point in the input space and uses it for the response. This is usually done at some sacrifice in the capability of the machine to learn all possible classifications and often with slower convergence to the classifications which it can learn. The objective then is to come as near simulating the ideal learning machine characteristics as possible with a practical machine using some other logical structure.

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Author's Comment[7]

It is a pleasure to answer Minsky's criticisms. I sincerely hoped for some violent reaction to my previous note. Minsky's points are: 1) that a learning machine should have "heuristic connections," and 2) that a machine should classify automatically quasi-same patterns in the same class because such small pattern variations are usually due to noise.

Minsky's first point is of little interest to me, because I am interested in gadgets performing certain tasks and not in how such gadgets do perform such tasks. The task I have in mind can be defined as follows: 1) the machine must classify a large but finite number of possible patterns in a set of classes chosen *a priori*, and 2) the machine must be able to change its classification when certain instructions are given. To this one can add that, from a user's point of view, the machine should be as small in size as possible, as versatile as possible and as rapid in learning a classification as possible. The versatility is measured by the number of different classifications the machine can learn.

The magnetic tape mentioned in my previous letter proves that we can today and without further ado make machines able to classify a considerable number of patterns in all possible ways and able to learn any classification desired at a given time within the least amount of time. The learning time is measured by the number of patterns in the trial sequence. Within the trial time, the machine must be told if its present output fits the classification required.

To tell the machine if it is right or wrong necessitates an *a priori* selected classification of patterns. The machine never creates its own classification. It can only do something of that sort in the paradoxical case where, because it cannot learn all possible classifications, the classification of a given pattern may be obtained without using that pattern as a trial pattern. Thus, what Minsky names an increase in knowledge while performing, is due to an inbuilt lack in information capability.

What bothers me most is that important tasks remain impossible, not because we cannot create a simple machine to perform them, but because the expectation that they should be done by a certain kind of complex machine has completely clouded the picture.

Minsky's second point is more subtle because the introduction of noise in a sense may justify the limitation of the machine to a smaller set of possible classifications. It should be remembered first, however, that sensing elements are threshold elements with a finite number of possible outputs so that in any case the number of possible input patterns, while large, is finite. Thus, the learning time of the tape-type machine is finite. One can, however, argue that, in the event many possible classifications are inacceptable, the learning time of such a machine is much longer than necessary. The elimination of noise by a series of averaging transformations over the outputs of the sensing elements is, however, not a characteristic of machines with "heuristic connections." This reduction of the number of patterns into a smaller set is an intrinsic part of a learning machine only if it itself can be modified within the learning periods. Otherwise it is only a pre-reduction of the number of patterns by a fixed classifier. Of course, such a pre-reduction of the number of patterns is easily done by a two-stage tape-type machine without having even to actually perform the averaging transformations. I can visualize a small library of first-stage tapes, each one determined by a given input noise level. For the noise level assumed, the corresponding first-stage tape will classify the patterns into a smaller set of inputs in such a way that all possible classifications of this smaller set are significant. A more sophisticated first-stage tape would give to each input pattern a probability in each element of the intermediary set so that the final output could take also into account the statistical nature of the inputs.

It is also a pleasure to answer Pryor's criticisms. They are basically the same as Minsky's, only similarity of patterns replaces distortion by noise. The generalization to a mathematical space does not represent truly the input patterns which always are finite in number. The complexity of the machines proposed to obtain some sort of learning from a reduction of the number of possible classifications is obvious even when the device is described in topological terms.

P. A. Clavier
Plasmadyne Corp.
Santa Ana, Calif.

M. L. Minsky[8]

What Clavier does not seem to recognize is that it is not enough to observe that a class "while large, is finite." So some believe, is the universe.

P. A. Clavier[9]

What Minsky does not seem to recognize is the small size of the largest raster of threshold elements one can hope for, compared not to the size of the universe but simply to the size of the memory of an existing large computer.

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[7] Received October 2, 1961; revised manuscript received, December 11, 1961.

[8] Received January 31, 1962.

[9] Received February 19, 1962.

On the Maximum Power Gain of a Two-Port Active Network*

Venkateswaran and Boothroyd[1] have shown that for a two-port active network the maximum available power gain for a given performance factor (n) is given by[2]

$$G_{\max,n} \simeq \frac{4}{n}\left|\frac{p_{21}}{p_{12}}\right|\left(1-\sqrt{\frac{n_i}{n}}\right)^2 \text{ for } n \gg 1, \qquad (1)$$

where the performance factor $n=\rho_1\rho_2/L$ and is a measure of amplifier stability. The determination of $G_{\max,n}$ involves the solution of a cubic equation, and it is stated[1] that the cubic has a single real root [which is subsequently employed to derive (1)] when $(L+M)/2L>1/9$ or $|N|>0.81|M|$. For a general active network such conditions would require the examination of the real and imaginary parts of $p_{12}p_{21}$ at the frequency of interest. Venkateswaran and Boothroyd state that when the active device is a transistor, one of the two conditions is almost always fulfilled in practice. It is the purpose of this communication to point out that a single real root is obtained for *any* device if $n>1$. The latter condition is independent of $p_{12}p_{21}$, and includes all amplifier configurations for which (1) is derived.

The general expression for the available power gain of a two-port active network is

$$G = \frac{4|p_{21}|^2 p_G p_L}{|p_1p_2 - p_{12}p_{21}|^2}. \qquad (2)$$

In order to determine the maximum G when the terminations p_G and p_L are variable, the denominator is first minimized. The denominator is written

$$D = (P-M)^2 + (Q-N)^2, \qquad (3)$$

where P and Q are defined by

$$P + jQ = p_1p_2 = (\rho_1 + j\sigma_1)(\rho_2 + j\sigma_2). \qquad (4)$$

It can be shown that because σ_1 and σ_2 are real,[3]

$$Q^2 - 4\rho_1{}^2\rho_2{}^2 + 4\rho_1\rho_2P \geq 0, \qquad (5)$$

and that for minimum D,

$$Q^2 - 4\rho_1{}^2\rho_2{}^2 + 4\rho_1\rho_2P = 0. \qquad (6)$$

Substitution of (6) in (3) gives

$$D = (Q-N)^2 + \left[\frac{4\rho_1{}^2\rho_2{}^2 - Q^2}{4\rho_1\rho_2} - M\right]^2. \qquad (7)$$

Equating dD/dQ to zero to obtain minimum D we obtain[4]

$$\lambda^3 + \lambda\left(1+\frac{M}{nL}\right) - \frac{N}{nL} = 0, \qquad (8)$$

where

$$\lambda = Q/2nL. \qquad (9)$$

The real root of (8) then gives the optimum value of Q and hence, from (5), the optimum value of P, and leads to the expression (1) for maximum gain.

The condition for a cubic $\lambda^3+a\lambda+b=0$ to possess a single real root is[5] that the discriminant Δ is greater than zero, where $\Delta=b^2/4+a^3/27$. For the cubic (8), Δ is given by

$$\Delta = \frac{1}{4n^3L^3}\left[nL\cdot N^2 + \frac{4}{27}(nL+M)^3\right]. \qquad (10)$$

For positive M, Δ is always >0 if $n>0$. For negative M, Δ is certainly greater than zero if $n>1$. Hence, if $n>1$, the cubic of (8) possesses a single real root, and no condition other than $n \gg 1$ must be satisfied in order to derive the expression (1) for maximum power gain.

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* Received, January 31, 1962.

[1] S. Venkateswaran and A. R. Boothroyd, "Power gain and bandwidth of tuned transistor amplifier stages," *Proc. IEE*, vol. 106B, suppl. 15, pp. 518–529; May, 1959.

[2] The terminology employed here follows that of Venkateswaran and Boothroyd.[1]

[3] A. P. Stern, "Stability and power gain of tuned transistor amplifiers," PROC. IRE, vol. 45, pp. 335–343; March, 1957.

[4] Eq. (8) is identical with (17) of Venkateswaren and Boothroyd.

[5] H. W. Turnbull, "Theory of Equations," Oliver and Boyd, London, Eng., p. 121; 1939.

A Threshold and Fan-In Reduction Algorithm for Threshold Functions*

The threshold function which results from recently discussed synthesis techniques such as Simplex, the Stram Algorithm and others, often requires a threshold level μ and/or a total weight factor M which is too great to be realized with hardware subject to the standard tolerances of the industry. The following is an algorithm by which one threshold element with a given μ and M can be broken into a number of threshold elements each with a smaller μ and M. Caution must be exercised in its use lest the original purpose of creating the threshold function be defeated. If the original intent were to minimize hardware, then the decomposed function should not exceed the hardware requirements of a Boolean synthesis; or if the original intent were to maximize speed then the number of levels should not exceed that of a Boolean synthesis.

Let the threshold function F be represented as follows:

$$F = (m_1x_1, m_2x_2, \cdots, m_rx_r; \mu), \qquad (1)$$

where m_i is the weight assigned to the variable x_i, and x_i may be barred or unbarred. In the context of a core solution a bar represents a reverse winding; in the context of a tunnel-diode solution a bar represents the absence of an input. (Also, an adjustment of μ is required when transforming from a core to a tunnel-diode realization.) The total number of input units is

$$M = \sum_{i=1}^{r} m_i, \quad \text{and} \quad F = 1$$

when the sum of the input units present is greater than μ.

Before proceeding to the algorithm, a useful reduction in μ can be obtained (but not in M) if μ is greater than $\frac{1}{2}M$, by a threshold logic theorem analogous to De Morgan's law, which could be called the De Morgan corollary; namely, if F is given by (1) then the De Morgan corollary states that

$$F = (m_1\bar{x}_1, m_2\bar{x}_2, \cdots, m_r\bar{x}_r; M - \mu + 1) \qquad (2)$$

THE μ REDUCTION ALGORITHM

First, a function F_1 can be extracted from F which involves only the first $r-1$ variables, has a reduced threshold level and leaves a residue also which involves only the first $r-1$ variables but still has the threshold μ. In symbols

$$\begin{aligned} F &= F_1x_r + R_1 \\ &= F_1x_r + (m_1x_1, m_2x_2, \cdots, m_{r-1}x_{r-1}; \mu), \end{aligned}$$

where

$$F_1 = (m_1x_1, m_2x_2, \cdots, m_{r-1}x_{r-1}; \mu - m_r)'$$

and

$$M_1 = \sum_{i=1}^{r-1} m_i.$$

Then, if both M_1 and $\mu - m_r$ are sufficient reductions, F_1 will satisfy the original criteria of μ and M reduction. The rule is now reapplied to the residue R_1. Thus,

$$R_1 = F_2x_{r-1} + R_2,$$

where

$$\begin{aligned} R_2 &= (m_1x_1, m_2x_2, \cdots, m_{r-2}x_{r-2}; \mu), \\ F_2 &= (m_1x_1, m_2x_2, \cdots, M_{r-2}x_{r-2}; \mu - m_{r-1}) \end{aligned}$$

and

$$M_2 = \sum_{i=1}^{r-2} m_i.$$

This process can continue recursively until an R_k is derived such that

$$M_k < \mu \qquad (3)$$

where

$$M_k = \sum_{i=1}^{r-k} m_i.$$

At this point the process stops because the residue R_k is not realizable. Then,

$$F = F_1x_r + F_2x_{r-1} + \cdots + F_kx_{r-k+1}.$$

The De Morgan corollary should be applied to each F_j to see if a further μ reduction is possible before testing for compliance with the original μ and M criteria. If a given F_j does not comply then it in turn must be reduced.

It has been found that the process terminates rather quickly when the m_i are arranged in ascending order (*i.e.* (3) obtains). In this way the μ reduction is very significant, being at least $\mu - m_{r-k+1}$.

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On Gravitational Waves and Nonlinear Electromagnetic Theory*

Interest in the general theory of relativity and gravitational waves has been renewed recently and several papers[1-3] on this subject have appeared lately in these PROCEEDINGS. Djurić[3] introduced the hypothesis of the gravitational-wave gh-field nature of light. In order to support his hypothesis, he pointed to several physical facts; one of them was that "the gravitational deflection of light also corroborates the basic hypothesis of the gh nature of light." Unfortunately, this statement is inaccurate, unless there is a mass density distribution ($\rho \neq 0$) in the static gravitational field. In other words, Einstein's nonlinear general theory of relativity and its space curvature gives, as a result, the deflection of light waves due to static gravitational field only, without any mass density distribution ($\rho = 0$); the same cannot be said for Djurić linear gh-field theory and his light hypothesis.

This can be shown as follows: assuming no mass density distribution ($\rho = 0$), the gh-field equation will become

$$\Delta x\bar{h} = \frac{1}{c^2}\,\frac{\partial \bar{g}}{\partial t}; \qquad \Delta x\bar{g} = -\,\frac{\partial \bar{h}}{\partial t} \tag{1}$$

for the static g_0h_0 field one gets $\nabla x\bar{h}_0=0$, $\nabla xg_0=0$. In case of a dynamic gravitational field superimposed on the static one, we have

$$\bar{g} = \bar{g}_0 + \bar{g}_1e^{iwt}; \qquad \bar{h} = \bar{h}_0 + \bar{h}_1e^{iwt}. \tag{2}$$

Substituting (2) into (1) we get

$$\nabla x\bar{h}_1 = \frac{1}{c^2}\,iw\bar{g}_1; \qquad \nabla x\bar{g}_1 = -\,iw\bar{h}_1. \tag{3}$$

Eq. (3) shows that there is no influence of the static gravitational field on the dynamic *gh* gravitational wave. The result is, therefore, in contradiction to Einstein's general theory of relativity prediction of the deflection of light in static gravitational fields with no mass density distribution and to the experimental results.

A corresponding result is quite well known in the classical electromagnetic theory and the magnetoionic theory. There is no interaction of the electromagnetic waves with (or deflection by) the static magnetic fields, unless there are charged particles in the same space. This statement applies as well to the case of inhomogeneous static magnetic field. Obviously, this result is based on the linear Maxwell equations.

This brings us to a very interesting point. Clavier[4] has shown that Maxwell's equations could be derived from the most general *linear* relationships between the electric field $\overline{E}$ and the magnetic field $\overline{H}$ and their sources. Let us suppose now that the electromagnetic fields in general behave according to more general *nonlinear* equations; under standard conditions the linear Maxwell equations could be derived by linearizing the general equations and neglecting the nonlinear terms. In a case when the nonlinear terms will not be neglected, the general nonlinear electromagnetic equations will apply, and there will be an interaction between the static magnetic field and the electromagnetic wave, even when there are no charged particles. In this case, the light electromagnetic waves might be deflected by the inhomogeneous static magnetic field around the sun, for example, and this deflection will be of second order of magnitude. Obviously, our experimental data is too limited to discuss this idea in any detail at the present time.

Another interesting point is the companionship between electromagnetic and gravitational waves. If an electron is oscillating in free space, by itself, it radiates electromagnetic waves; at the same time its mass is oscillating and produces gravitational waves by similar analytical process. Both waves are propagating with the velocity of light in free space; therefore, one can deduce that every electromagnetic wave is accompanied by a corresponding gravitational wave.

One last remark. In a recent correspondence, McMurtrey[5] found some "fallacies" in the Dirac delta-function Fourier-integral representation. It should be pointed out that a very good discussion on the subject of the Fourier continuous spectrum of the Dirac delta-operator function, which explains the above mentioned "fallacies" may be found in a book by Friedman.[6] Also they could be explained if one expresses the Dirac delta-operator function by the well-known relation as a limiting case:

$$\begin{aligned}\delta(t) &= \lim_{\alpha\to 0}\delta(t,\alpha) = \lim_{\alpha\to 0}\frac{1}{\pi}\,\frac{\alpha}{\alpha^2+t^2}\\ &= \lim_{\alpha\to 0}\frac{1}{\pi}\int_0^{\infty} e^{-\alpha\omega}\cos\omega t d\omega\\ &= \lim_{\alpha\to 0}\frac{1}{2\pi}\int_{-\infty}^{+\infty} e^{-\alpha|\omega|}\cos\omega t d\omega\\ &= \lim_{\alpha\to 0}\frac{1}{2\pi}\int_{-\infty}^{+\infty} e^{-\alpha|\omega|}e^{i\omega t}d\omega \end{aligned} \tag{4}$$

Eq. (4) could be proved easily.

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Author's Reply[7]

The critical comments of Dr. Unz dwell on three different papers, and I shall confine myself to comment on his remarks concerning my papers only.

Unfortunately, the statement of Dr. Unz that the statement that "the gravitational deflection of light also corroborates the basic hypothesis of the *gh* nature of light" is inaccurate, is incorrent, *i.e.*, wrong. Namely, Dr. Unz has failed to notice that a dynamic *gh* field in the presence of a "static" gravitational field is a typical boundary-value problem; and, therefore, such a dynamic *gh*-field boundary-value problem *cannot* be treated in the simple way proposed by Dr. Unz in his equations (1)–(3). If the problem is approached correctly and rigorously, it can be shown that the presence of mass, which creates the "static" gravitational field, will disturb a dynamic *gh* field created by some different sources in the same way as the presence of the earth, for instance, causes the deflection of the electromagnetic waves. Dr. Unz has actually failed to notice the analytic identity of those two problems. However, Dr. Unz is aware of the fact that there is an interaction of the electromagnetic waves with the "static" magnetic field if there are charged particles in the same space. This statement translated into the *gh*-field theory leads to the same corollary exposed above. Of course, the influence of mass, *i.e.*, charge in the case of the electromagnetic field , decreases with the distance from the mass, but a dynamic *gh* field is definitely disturbed in the vicinity of masses.

It should be also emphasized that a *purely "static"* gravitational field *does not exist* in nature, and the rigorous treatment of the deflection of a dynamic *gh* field in the presence of the other mass system is quite complex.

A further statement of Dr. Unz that "every electromagnetic wave is accompanied by a corresponding gravitational wave" is not acceptable from the point of view of my unified-field theory, which I developed some time ago, long before my two communications were sent to the IRE, and which, I hope, will be published soon by a scientific journal.

Namely, it is strange to assume that an oscillating charge can create two separate fields: electromagnetic and gravitational, *i.e.*, *gh*. It is even more strange that those two fields are analytically, *i.e.*, geometrically, identical. There must be a union between those two fields. And that union really exists. Moreover, there is only one unique field, *gh* or *BE*, since those two fields are identical and only differ in the scale, as well be shown presently.

This can be shown immediately if we notice the strange asymmetry of the Maxwell equations. Namely, both div $\boldsymbol{h}$, and div $\boldsymbol{B}$ are equal to zero, while div $\boldsymbol{g}$ and div $\boldsymbol{E}$ are different from zero. There is no physical evidence at present as to the existence of magnetic poles, but it is a well-known fact that electric charges can create a field which is antigravitational, namely an electric field. If we assume that divergence of the antigravitational field $\boldsymbol{h}$ is equal to the charge density multiplied, of course, by a suitable constant which depends on the system of units, we immediately obtain a perfect symmetry of the field equations, which I call the modified Maxwell equations of the *gh* field. Due to that modification the expression for force must be also modified, introducing two

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* Received by the IRE, December 7, 1961.

[1] R. L. Forward, "General relativity for the experimentalist," PROC. IRE, vol. 49, pp. 892–904; May, 1961.

[2] J. Djurić, "Gravitational fields," PROC. IRE, vol. 49, p. 1689; November, 1961.

[3] J. Djurić, "The gh field theory," PROC. IRE, vol. 49, p. 1690; November, 1961.

[4] P. Clavier, "Electromagnetic theory from a mathematical viewpoint," PROC. IRE, vol. 48, pp. 1494–1495; August, 1960.

[5] A. W. McMurtrey, "The delta function and the fourier integral," PROC. IRE, vol. 49, pp. 1702–1703; November, 1961.

[6] B. Friedman, "Principles and Techniques of Applied Mathematics," John Wiley & Son, Inc., New York, N. Y., pp. 217–221; 1956.

[7] Received by the IRE, January 2, 1962.

additional terms, so that altogether we have four terms for force. It becomes obvious from that force expression that the gravitational field $\mathfrak{g}$ is identical to the magnetic field $\boldsymbol{B}$, while the antigravitational field $\boldsymbol{h}$ is identical to the electric field $\boldsymbol{E}$, with, of course, suitable constants of proportionality depending on units.

The union is thus accomplished between the *gh* field and the electromagnetic field, since they are really identical, and that union is broken only in the theoretical static case, when the field equations reduce to the Newton field and the Coulomb field separately.

Although the union is accomplished formally, the immediate conclusions are obvious and of far-reaching consequences. The conclusions are as follows:

1) Masses and charges in movement create a unique field of two vectors.

2) A magnetic field, *i.e.*, a gravitational field, exerts a translatory force upon a neutral mass particle as well as a force upon a moving electrical charge.

3) An electric field, *i.e.*, an antigravitational field, exerts a translatory force upon a charged particle as well as a force upon a moving neutral mass particle.

4) Masses, as well as moving charges, create a gravitational field, *i.e.*, a magnetic field, which may be rather weak in the macroscopic case due to masses only.

5) Charges, as well as moving masses, create an electric field, *i.e.*, an antigravitational field.

6) The modified field equations definitely provide a possibility of expressing electrical charge in terms of moving masses, or mass in terms of moving electrical charges. Mass and charge are two interwoven entities, so closely united that they cannot be treated separately. They are two forms of a unique physical reality.

7) The variation of mass with velocity is due to a force term which has not been taken into account so far.

8) The unified-field theory contains in itself the Newton gravitational theory, as well as the Maxwell electromagnetic theory, at least for the macroscopic case, and, therefore, all the results of those two theories are immediately obtainable from the unified-field theory in a straight-forward way. The unified-field theory provides the union of those two so far separate fields.

Numerous experimental facts indicate an excellent qualitative agreement with the unified-field theory, to mention only the deflection of neutron in the "nonhomogeneous" magnetic field, but further experiments and measurements are necessary to prove or disprove that theory.

A paper of mine exposing my unified-field theory analytically has been sent to a scientific journal, and is at present being reviewed for publication.

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[8] On leave of absence 1961–1962; teaching in the Dept. of Elec. Engrg., University of New Mexico, Albuquerque, N. M.

A Property of Linear Frequency Modulation*

A fact useful in connection with chirp radars is that a linear FM signal of arbitrary envelope, when passed through a suitable network with linear delay characteristic, suffers a reversal of the linear FM and a Fourier transformation of the functional form of the envelope. It is shown here that no other FM signal and delay network are related in this way, *i.e.*, in respect to Fourier transformation of the arbitrary envelope, reversal of a summand of the input phase, and reproduction of the complementary summand.

Recently Klauder, *et al.*,[1] in an analysis of chirp radars, derived the following result which they describe as important and exceedingly general. Suppose a *linear frequency modulated* signal, represented by the complex waveform

$$s_1(t) = E(t) \exp\{2\pi i(f_0 t + kt^2/2)\},$$

where k is a real constant and f_0 the carrier frequency, is passed through a *linear delay network* with admittance function

$$\tilde{y}(f) = \exp\{\pi i(f - f_0)^2/k\}.$$

Then the output signal has waveform

$$s_2(T) = (ki)^{1/2}\tilde{E}(-kT) \exp\{2\pi i(f_0 t - kt^2/2)\};$$

that is, regardless of the envelope $E(t)$ of the original signal, the linear FM has been reversed in direction and the functional form E of the envelope has been replaced by its Fourier transform $\tilde{E}$.

We will show that this situation uniquely *characterizes* linear FM signals and linear delay networks, in a rather broad sense. Specifically, replace $s_1(t)$ and $\tilde{y}(f)$ respectively by the *general* waveform and *general* delay characteristic

$$S_1(t) = E(t) \exp\{2\pi i F(t)\},$$

$$\tilde{Y}(f) = \exp\{2\pi i G(f)\}$$

and consider *any* decomposition $F(t) = F_e(t) + F_0(t)$, where the first summand corresponds to $kt^2/2$ in $s_1(t)$, and the second summand corresponds to $f_0 t$. Then the relationship among $s_1(t)$, $\tilde{y}(f)$ and $s_2(T)$ is "naturally" generalized by requiring the existence of non-zero constants A and (real) k, *independent* of the envelope $E(t)$ of $S_1(t)$, such that the output when $S_1(t)$ is passed through the network described by $\tilde{Y}(f)$ is

$$S_2(T) = A\tilde{E}(-kT) \exp\{2\pi i(F_0(T) - F_e(T))\}.$$

What will be proved is that this relationship *implies* that $S_1(t)$ represents linear FM and $\tilde{Y}(f)$ represents linear delay.

For the proof, rewrite the desired output form as[2]

$$S_2(T) = (2\pi)^{-1/2} A \int E(t) \cdot \exp\{2\pi i(F_0(T) - F_e(T) - kTf)\}\,dt.$$

The actual output form is readily found to be

$$S_2(T) = (2\pi)^{-1} \int E(t) \left[\int \exp\{2\pi i(F_0(t) + F_e(t) - tf + G(f) + Tf)\}\,df \right] dt,$$

and the two can coincide, for *arbitrary* input envelopes $E(t)$, if, and only if,

$$(2\pi)^{-1/2} \int \exp\{2\pi i((T - t)f + G(f))\}\,df = A \exp\{\pi i(F_0(T) - F_0(t) - F_e(T) + kTt)\}.$$

It is perhaps more physically meaningful to introduce the admittance function $Y(t)$ of the network, in the *time* domain, as the inverse Fourier transform of $\tilde{Y}(f)$. The preceding condition becomes

$$Y(T - t) = A \exp\{2\pi i(F_0(T) - F_0(t) - F_e(T) + kTt)\}$$

but setting $T = t$ leads quickly to the conclusion $F_e(t) = (C + kt^2)/2$ where C is a constant, so that the equation becomes

$$Y(T - t) = A \exp\{2\pi i(F_0(T) - F_0(t) - C - k(T - t)^2/2)\}.$$

This implies that $F_0(T) - F_0(t)$ depends only on $T - t$, which in turn implies that F_0 is a linear function whose slope will be denoted f_0. Thus

$$F(t) = F_e(t) + F_0(t) = C_1 + f_0 t + kt^2/2 \qquad (C_1 = \text{constant}),$$

so that $S_1(t)$ represents linear FM. Also, setting $t = 0$ in the equation for $Y(T - t)$ and then taking the Fourier transform leads to

$$\tilde{Y}(f) = C_2 \exp\{\pi i(f - f_0)^2/k\} \qquad (C_2 = \text{constant})$$

so that the network has a linear delay characteristic.

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* Received December 26, 1961; revised manuscript received February 9, 1962.

[1] J. R. Klauder, A. C. Price, S. Darlington, and W. J. Albersheim, "The theory and design of chirp radars," *Bell. Sys. Tech. J.*, vol. 39, pp. 745–808; July, 1960.

[2] All integrals are taken over the entire real axis.

Prevarication vs Redundancy*

Weak interference in a communication link is annoying, but it does not significantly reduce the amount of information conveyed by the link, since the errors caused by the interference can generally be corrected by anyone who knows the language of the messages. They are corrected by making use of the "redundancy" of the language, *i.e.*, the constraints imposed by the letter and multiple-letter frequencies, the rules of spelling and grammar, and the necessity that the message make sense. When the interference is sufficiently strong or redundancy is lacking, it is not possible to reconstruct the original message uniquely from the received version.

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Information, Equivocation and Prevarication: To make this notion more precise, we make use of Shannon's measure[1] of the amount of information conveyed when a message x is transmitted and another message y is received, expressed in the same alphabet as the transmitted message x. The processes of representing x by a transmitted signal and of determining what y the receiver should deliver on the basis of the (corrupted) received signal will be regarded as part of the communication channel, whose input is x and whose output is y.

We denote by $H(x)$ the entropy of the transmitted message x, *i.e.*, the prior uncertainty as to which message has been transmitted, and we denote by $H(x|y)$ the conditional entropy of x when the received message y is known, *i.e.*, the average posterior uncertainty as to which transmitted message resulted in the message that was actually received. Shannon has given the name "equivocation" to $H(x|y)$. The amount of information conveyed under these circumstances is measured by the reduction in the uncertainty as to x resulting from the reception of y, *viz.*,

$$I(x; y) = H(x) - H(x|y) \tag{1}$$

These quantities are not functions of x or y but are averaged over all possible x and y. From (1) we see that the equivocation $H(x|y)$ measures the information loss that occurs in the communication channel, since $H(x)$ measures the information being transmitted.

If we denote the prior uncertainty as to which message will be received by $H(y)$ and the posterior uncertainty when the transmitted message is known by $H(y|x)$, it can be shown by means of Bayes's theorem that

$$I(x; y) = H(y) - H(y|x). \tag{2}$$

It is convenient to refer to $H(y|x)$ as the "prevarication."[2] The prevarication measures the average uncertainty as to what will be received when a given message is transmitted.

Criterion of Seriousness: Since strong interference may not completely prevent the transmission of information, but leave considerable equivocation or uncertainty as to what message was sent, and weak interference essentially has no effect, the seriousness of interference may be measured by the information loss or the ambiguity it causes as to the transmitted message in spite of the latter's redundancy, *i.e.*, by the equivocation it introduces. This criterion is very similar to the one used by Shannon to measure the "theoretical secrecy" of a cryptographic system when a cryptogram has been intercepted, *viz.*, the equivocation of the (clear) message.[3] As the length of the intercepted cryptogram increases beyond a certain point, the redundancy of the message causes the equivocation to fall until finally no uncertainty remains as to what message the cryptogram represents, even though the key, which introduces a certain prevarication, is not intercepted.

Redundancy: If b is the number of symbols in the alphabet used to construct messages, there are b^n different possible messages of length n. If all of them were equally likely, the prior uncertainty as to a message of length n would be $H(n) = \log b^n = n \log b$. Because of the constraints of the language, only a small fraction of these are ever used, and this fraction falls exponentially with increasing n. Thus, the actual prior uncertainty $H(x)$ as to which message (of length n) has been chosen for transmission is much smaller than $H(n)$. The difference between these two entropies

$$D(n) = H(n) - H(x) \tag{3}$$

measures the effect of the redundancy of the language; only a fraction of the order of $2^{-D(n)}$ of the possible transmitted messages are ever sent. For ordinary English, when constraints acting over distances up to eight letters are taken into account, the redundancy is found to be about 50 per cent, *i.e.*, $D(n)$ is about half of $H(n)$ for large n.[4] When grammar and meaning are taken into account the redundancy may increase to 75 per cent or more, depending on the nature of the text.

Fundamental Inequality: Making use of (1) and (2), we can write the equivocation as $H(x|y) = H(y|x) - H(y) + H(x)$. We shall assume that received message y has the same length n and same alphabet size b as the transmitted message x; hence, the prior uncertainty $H(y)$ as to which n-symbol message will be received cannot exceed the uncertainty $H(n)$ associated with a completely random sequence of n symbols. Thus, the equivocation must satisfy the inequality $H(x|y) \geq H(y|x) - H(n) + H(x)$ or from (3),

$$H(x|y) \geq H(y|x) - D(n), \tag{4}$$

i.e., the equivocation cannot be less than the difference between the prevarication and the redundancy.

In many communication systems the prevariation, which is due to errors in transmission, is independent of the transmitted message. The redundancy, on the other hand, depends only on the constraints of the language.

From (4) we see that no matter how high the redundancy is, equivocation can be introduced by making the prevarication bigger. A sufficient interference power to cause ambiguity as to which message was sent, then, is the value that yields a prevariation equal to the redundancy, and this power can be determined from the statistics of the effect of the interference on the received message.

Looked at from another point of view, (4) provides a necessary (but not sufficient) condition for unequivocal communication, *viz.*, that the prevarication does not exceed the redundancy. Thus, for successful (unequivocal) communication, the interference power must not exceed the level for which the prevariation equals the redundancy.

It would be desirable to have sufficient as well as necessary conditions for successful communication. Unfortunately, it appears difficult to find a nontrivial sufficient condition. In practical circumstances it is possible to guarantee, by suitable encoding of the message, that the equivocation is arbitrarily small but not that it vanishes. This can be done, of course, only with redundancy at least as great as the prevarication.

The importance of redundancy in combating noise has long been known. Since there is almost no redundancy in the numbers that appear in telegraph messages, any error rate, however small, would result in ambiguity in the numerical parts of messages. Numbers are therefore either spelled out or are repeated, thus introducing a redundancy comparable to that of the rest of the text.

Application to Teletype: In teletype communication each of the 32 characters is represented by a sequence of five binary elements, "mark" or "space," preceded by a "start" signal and followed by a "stop" signal. Thus, the messages are written in a binary alphabet, and $b = 2$. Because the start and stop signals are completely predictable, they may be ignored.

When interference causes each of the five information elements to be received incorrectly with probability p, with all errors statistically independent, the interference introduces a prevarication of $-p \log p - (1-p) \log (1-p)$ per code element. If the redundancy of teletype messages is 50 per cent, *i.e.*, 0.5 bit per code element, p must exceed 0.1107 for the prevarication to exceed the redundancy. Thus, the interference will necessarily succeed in causing an equivocation (ambiguity) if it is strong enough to cause an average of about one error in nine binary elements.

If each of the five information elements of a character has a probability of error p, the probability that the character is received incorrectly is $1-(1-p)^5$, which for $p = 0.1107$ is 0.441, *i.e.*, about four characters in nine will be received incorrectly. However, although these characters are wrong, they give information about the transmitted message, since it is likely that the correct character is one of the five differing in only one element from the received character.

If, instead, the communication system were such that all 31 wrong characters were equally likely whenever an error occurred, the probability of error would have to be 0.322 for each character in order to make the prevarication equal the redundancy, assumed to be 50 per cent of 5 bits per character. The lower error rate which is tolerable here results from the fact that the erroneous characters convey no information as to the correct characters. This result has been tested experimentally, and it appears to be about right.[5]

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[1] C. E. Shannon, "A mathematical theory of communication," *Bell Sys. Tech. J.*, vol. 27, pp. 379–423, July, 1948; pp. 623–656, October, 1948.

[2] N. M. Blachman, "Minimum-cost encoding of information," IRE TRANS. ON INFORMATION THEORY, vol. PGIT-3, pp. 139–149; March, 1954.

[3] C. E. Shannon, "The communication theory of secrecy systems," *Bell Sys. Tech. J.*, vol. 28, pp. 656–715; October, 1949.

[4] C. E. Shannon, "Prediction and entropy of printed English," *Bell Sys. Tech. J.*, vol. 30, pp. 50–64; January, 1951.

[5] Also see A. Hauptschein and L. S. Schwartz, "Semantic constraints in the analysis of communication systems," PROC. IRE, vol. 45, pp. 1284–1285; September, 1957.

Phase Measurements of CW Transmissions at 80 kc Over a 1900-km Path*

The Defence Research Telecommunications Establishment is making a series of experiments for the purpose of studying the lower ionosphere at high latitudes by the propagation of LF radio waves. In one of these experiments the phase and amplitude of 80-kc stable frequency transmissions from a transmitter at Ottawa are recorded at Churchill, 1900 km distant. Continuous measurements have been made since July, 1960. A record of the variation of phase for the month of November, 1960, during which several major ionospheric disturbances occurred, is shown in Fig. 1. The gross parabolic change of phase[1] is due to relative drifts between terminal oscillators. A parabolic curve fitted to the daytime values by the method of least squares, is shown as a dashed curve in Fig. 1 and represents a drift of about 7 parts in 10^{11} per day. Departures from this dashed curve are almost entirely due to propagation variations, and these, for the period from November 10–15, are shown in Fig. 2. The relative field strength variations are also shown (except for November 12–13 when the amplitude pen stopped inking). The short vertical lines mark the times when the zenith angle of the sun is 102° and 90° 50′ (ground sunrise and sunset) at the path midpoint.

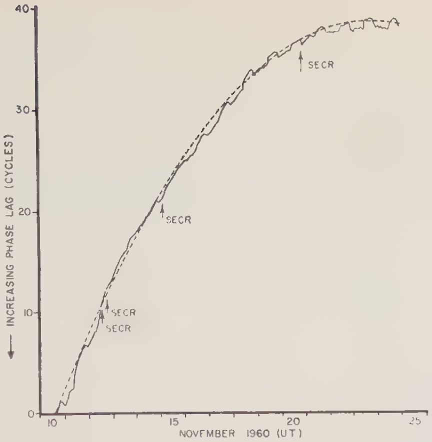

Fig. 1—Continuous record of phase measured at Churchill from an 80-kc transmitter at Ottawa. The vertical arrows with captions SECR mark the times of the beginning of sudden enhancements of cosmic rays observed at Ottawa and Churchill.

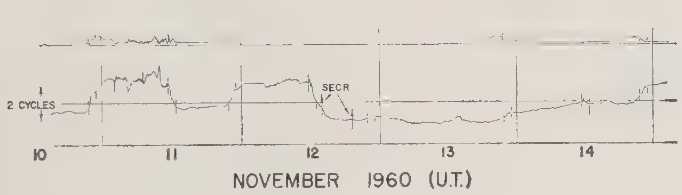

Fig. 2—LF propagation recordings of phase and amplitude made at Churchill of 80-kc transmissions from Ottawa.

In interpreting these phase records, there is good reason to assume that the predominant propagation mode is a singly reflected skywave, since this path is the one of minimum phase, and that changes in phase are associated with changes in the height of reflection. The skywave intensity at these distances is large compared with the ground wave. According to this interpretation the diurnal change of phase of 1.2–1.8 cycles during undisturbed days represents a change in reflection height of 16–25 km. Other evidence suggests that LF waves propagated over these distances are reflected from heights below 70 km by day, perhaps near 65 km; the corresponding nighttime reflection heights are 80–90 km.

When the propagation path is undisturbed, as during November 10–11, 1960, the daytime field strength is relatively constant, slow and regular fading occurs at night, and oscillatory features associated with the formation and decay of ionization in the lowest ionosphere occur near sunrise and sunset. The phase is relatively constant by day, and the change from night-to-day occurs during twilight at the path midpoint.

Following the large solar flare of November 12, a solar cosmic ray event, or so-called polar cap disturbance event, began. The ionospheric disturbance associated with this event, although not unique, was of unprecedented magnitude, and resulted in great absorption of HF and VHF waves, and with a decrease in relative phase lag of the 80-kc transmissions. Our results for this event have been separately reported.[2,3] From the decrease in phase lag we suggested that during November 12–13 the waves were reflected from heights some 10–12 km below normal, *i.e.*, from heights of 50–55 km. This suggestion is to some extent supported by our observation, in recent months, of partial reflections of 2.6- and 6.2-Mc waves at these heights at Ottawa, during other similar disturbances.

Other experimenters have reported on phase measurements of 100-Kc pulse transmissions.[4] A confusing feature of these observations is the reported fact that the skywave phase of a particular mode, *e.g.*, first hop sky wave, is remarkably constant whereas the amplitude is quite variable. In addition it is reported that high order multihop skywaves were observed at all transmission distances, and in fact the amplitude of these waves could exceed that for the least time mode. As a result of these observations the authors caution against the assumption that phase changes of CW transmissions are associated with reflection height changes. Our observations, using quite different techniques and locations, indicate that the total field strength does not vary wildly, that phase changes during normal and disturbed conditions are consistent with expected changes in the reflection height, and that the least time mode (one hop skywave) is the predominant mode at all times. If changes in propagation mode frequently occurred, they should be accompanied by discontinuous phase changes, and the regular trend shown in Fig. 1 would not be recorded. There is thus an apparent divergence between the phase measurements described here, and the observations reported by Doherty, *et al.*[4]

J. S. Belrose
Defence Res. Telecommun. Establ.
Defence Res. Board
Ottawa, Canada

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* Received January 22, 1962.

[1] J. A. Pierce, "Intercontinental frequency comparison by very low frequency radio transmission," Proc. IRE, vol. 45, pp. 794–803; June, 1957.

[2] J. S. Belrose and D. B. Ross, "Observations of unusual low-frequency propagation made on 12 November, 1960," *Canad. J. Phys.*, vol. 39, pp. 609–614; April, 1961.

[3] J. S. Belrose and D. B. Ross, *Proc. Symp., Internatl. Conf. on Cosmic Rays and the Earth Storm*, Kyoto, Japan; September, 1961 supplement to the *J. Phys. Soc. Japan* (in press).

[4] R. H. Doherty, G. Hefley and R. F. Linfield, "Timing Potentials of Loran-C," Proc. IRE, vol. 49, pp. 1659–1673; November, 1961.

The Constancy of the Velocity of Light*

I am rather surprised to see the old classical arguments concerning a test for the constancy of the velocity of light raised once again by Gordon.[1]

It was adequately demonstrated as long ago as 1934 by the English mathematician-philosopher Dunne in his work, "The Serial Universe,"[2] Chapter XIII, that one cannot determine the value of c without taking into account the serial nature of time.

It is also demonstrated in Chapter XVI of the same book that to any observer traveling along his world line with a velocity t, the velocity of light will be

$$c = \sqrt{-1} \times t \quad \text{or} \quad c = it$$

and this value will be a limiting velocity inasmuch as nothing used for a signal will be able to travel at a higher speed.

Therefore, this limiting velocity (of light) can only change for that observer if the velocity of his "now" point changes along his world line.

In view of the importance of Dunne's work (reprinted in 1955), it is surprising how few people have read it. I can assure Mr. Gordon that it is recommended reading. I hasten to add that I have no connection with the author (now deceased) or the publisher.

A. E. Lott
6, Richmond Road
Caversham Heights
Reading, Berks.
United Kingdom

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* Received February 5, 1962.

[1] C. K. Gordon, Jr., "A proposed test for the constancy of the velocity of light," Proc. IRE, vol. 49, pp. 1953–1954; December, 1961.

[2] J. W. Dunne, "The Serial Universe," Faber and Faber, Ltd., London, England; 1934.

Contributors

Denzil J. Doyle was born in Vinton, Quebec, Canada, on April 16, 1932. He received the B.Sc. degree in electrical engineering from Queen's University, Kingston, Ontario, in 1956.

He joined the staff of the Defence Research Telecommunications Establishment of the Defence Research Board, Ottawa, in 1957, where he has been engaged in studies on HF communications systems. Prior to this, he was engaged in electronic development work with Computing Devices of Canada, Ottawa, for a period of approximately eighteen months.

❖

Hubert Heffner (S'49–A'52–SM'56–F'62) was born in Lincolnton, N. C., on December 26, 1924. He received the B.S. degree in physics, in 1947, and the M.S. and Ph.D. degrees in electrical engineering, in 1949 and 1952, respectively, from Stanford University, Calif. From 1949 to 1951 he was a predoctoral fellow of the Atomic Energy Commission.

During World War II he served in the U. S. Army Signal Corps, and was in charge of several microwave relay stations in Germany. From 1952 to 1954 he was on the technical staff of Bell Telephone Laboratories, where he was engaged in vacuum-tube research. Since 1954 he has been on the faculty of Stanford University, and is now Professor of Electrical Engineering.

Dr. Heffner is a member of Phi Beta Kappa, Sigma Xi and the American Physical Society.

❖

G. William Irvine (SM'56–M'58) was born in Vulcan, Alberta, Canada, on July 12, 1931. He received the B.A.Sc. degree in electrical engineering from the University of British Columbia, Vancouver, in 1958.

Prior to his studies at the University, he spent three years in the Royal Canadian Horse Artillery. In 1958 he joined the Defence Research Telecommunications Establishment of the Defence Research Board, Ottawa, Canada, and has been engaged in studies on HF communications systems.

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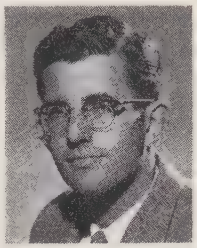

George W. Jull was born in Calgary, Alberta, Canada, on June 22, 1929. He received the B.Sc. degree in engineering physics from the University of Alberta, in 1951, and the DIC and Ph.D. degrees in electrical engineering after postgraduate studies at Imperial College, University of London, England.

In 1955, he returned to Canada, and since that time he has been engaged in communications systems studies at the Defence Research Board, Ottawa.

Dr. Jull is a member of the Canadian Association of Physicists and the Association of Professional Engineers of the Province of Ontario.

❖

Stewart M. Krakauer (A '54–M'60), for a photograph and biography please see page 100 of the January, 1962, issue of these Proceedings.

❖

Robert L. Kyhl (M'58) was born in Omaha, Neb., on July 27, 1917. He received the S.B. degree from the University of Chicago, Ill., in 1937, and the Ph.D. degree in physics from Massachusetts Institute of Technology, Cambridge, in 1947.

During World War II he was employed at the Radiation Laboratory, M.I.T., where he worked on magnetrons and microwave test equipment. From 1948 to 1954 he was at the W. W. Hansen Laboratories at Stanford University, Calif. working on the Microwave Electron Linear Accelerator Project. He spent two years at the G.E. Research Laboratories, Schenectady, N. Y., working on high-power microwave tubes. Since 1956 he has been Associate Professor in the Department of Electrical Engineering at M.I.T. and a member of the microwave spectroscopy laboratory of the Research Laboratory of Electronics, where he is studying paramagnetic resonance in solids and related maser problems.

Dr. Kyhl is a member of the American Physical Society.

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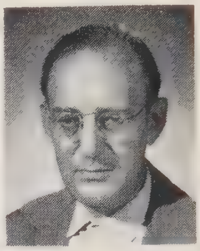

Leonard R. Malling (A'31–VA'39–M'59) was born in London, England, on July 9, 1909. He graduated from Northampton Technical Institute, London, in 1931, and came to this country in 1938.

For some thirty years he has done research and design engineering in such areas as television, radar, nuclear resonance, aircraft, missile guidance, and space communications. He has been employed at Electrical and Musical Industries, the Baird Television Company, Hazeltine Electronics Corporation, Boeing Airplane Company, Convair, Varian Associates, and the U. S. Naval Laboratory, San Diego. In 1955 he joined the staff of the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, where he is presently an Electronics Specialist.

❖

Ross A. McFarlane (S'52–M'59) was born in Toronto, Ontario, Canada, on June 10, 1931. He received the B.Sc. degree in physics from McMaster University, Hamilton, Ontario, in 1953, and the M.Sc. and Ph.D. degrees, in 1955 and 1959, respectively, from McGill University, Montreal, Canada.

He was a staff member of the Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, from 1959 to 1961, where he worked in the field of broad-band microwave masers. In June, 1961, he joined the Bell Telephone Laboratories, Murray Hill, N. J., and is at present engaged in optical maser research.

Dr. McFarlane is a member of the Canadian Association of Physicists.

John P. Murray was born in Ottawa, Canada, on January 29, 1935. He received the B.Sc. degree in electrical engineering from Queen's University, Kingston, Ontario, in 1957.

In 1957 he joined the Defence Research Telecommunications Establishment of the Defence Research Board, Ottawa, working in the field of UHF radars. He has been engaged in the field of HF communications systems and frequency sounding systems for the past two years.

Mr. Murray is a member of the Professional Engineers of the Province of Ontario.

⁂

Benjamin Rabinovici (SM'58) was born in Vaslui, Rumania, on May 17, 1922. He received the diploma in electrical engineering from the Polytechnic University of Bucharest, in 1948, and the M.S.E.E. degree from Columbia University, New York, N. Y., in 1955.

After entering the U.S.A., he worked from 1951 to 1956 for C.B.S. Columbia, New York, N. Y., as a Senior Engineer in the Advance Development Laboratory on monochrome and color TV circuitry. From 1956 to 1957 he was a Senior Project Engineer with the Electronic Computer Division of Underwood Corp., Long Island City, N. Y., working in the area of ferroelectric and magnetic core memories. He was a member of the staff of IBM Watson Research Laboratory at Columbia University, from 1957 to 1960, leading a group engaged in research on superconducting computer devices and circuitry. Since 1960 he has been associated with RCA Surface Communications Division, New York, N. Y., where he is directing a group active in the field of Solid-State Digital Communications Techniques.

Mr. Rabinovici is a member of the American Physical Society, AAAS, and Eta Kappa Nu.

Charles A. Renton (M'61) was born in London, England, in 1930. He received the B.Sc. degree from London University, in 1950, and the D.Phil. degree from Oxford University, in 1954, for research in superconductivity.

From 1954 to 1956 he was at Pennsylvania State University, University Park, first as Research Associate and then as Assistant Professor. From 1956 until 1960 he was on the technical staff at Bell Telephone Laboratories, Murray Hill, N. J. During these years his research was in the field of low temperature solid-state physics. In 1960 he joined RCA Surface Communications Division, New York, N. Y., where he is engaged in research on advanced circuit techniques.

Dr. Renton is a member of the American Physical Society and the Physical Society (London).

⁂

Malcolm W. P. Strandberg (A'42–SM'51–F'59) was born in Box Elder, Mont. on March 9, 1919. He received the B.S. degree, in 1941 from Harvard University, Cambridge, Mass., and the Ph.D. degree, in 1948, from the Massachusetts Institute of Technology, Cambridge.

From 1941 to 1945 he was a staff member of the Radiation Laboratory, M.I.T., where he was engaged in advanced development work on microwave radar. He spent the year 1945 to 1946 in Malvern, England, as a Visiting Scientist working on radar countermeasures for the Royal Air Force. He was Research Assistant in Physics at M.I.T. from 1945 to 1948, was appointed Assistant Professor of Physics in 1948, Associate Professor in 1953, and Professor of Physics in 1960. He is now head of a research group in microwave spectroscopy in the Research Laboratory of Electronics, M.I.T.

Dr. Strandberg is a Fellow of the American Physical Society, the American Academy of Arts and Sciences, the New York Academy of Arts and Sciences and the AAAS. He was a Visiting Scientist for the American Institute of Physics in 1957–1958 and 1958–1959, and is now a Fulbright Lecturer for the year 1961–1962 at the University of Grenoble, France. He is also a member of Phi Beta Kappa.

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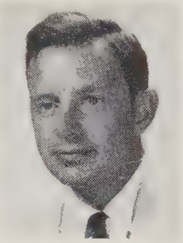

James R. Wait (SM 56–F'62) was born in Ottawa, Ontario, Canada, on January 23, 1924. During World War II, he was in charge of a radar maintenance group at Kingston, Ontario. He received the B.A.Sc. and M.A.Sc. degrees in engineering physics, in 1948 and 1949, respectively, and the Ph.D. degree in electromagnetic theory, in 1951, all from the University of Toronto, Ontario.

While completing his studies he was associated with Newmont Exploration Ltd. of New York, N. Y., and Jerome, Ariz. From 1952 to 1955 he was a Section Leader in the Defence Research Telecommunications Establishment, Ottawa, primarily concerned with theoretical problems in radiation. Since joining the National Bureau of Standards, Boulder, Colo., in 1955, he has concentrated on the theoretical aspects of LF radio propagation. He is presently Consultant on radio wave propagation in the Office of the Director of the Boulder Laboratories.

From 1958 to 1961 he served as the initial Editor of the *Radio Propagation Journal* (Section D of the NBS *Journal of Research*). He is now an Associate Editor of the *Journal of Geophysical Research*. In the fall of 1960, he visited the Technical University of Denmark, Copenhagen, to help establish a research laboratory in electromagnetic theory. In 1961 he was appointed Professor (adjoint) of Electrical Engineering by the University of Colorado, Boulder. He is Chairman of the technical program of the URSI Symposium on Electromagnetic Theory to be held in Copenhagen in June, 1962.

Dr. Wait is a member of the Research Society of America, the Canadian Association of Physicists, the American Geophysical Union, the Society of Exploration Geophysicists, and Commissions 2, 3, and 6 of the International Scientific Radio Union (URSI)

Books

Electronic Amplifier Circuits: Theory and Design, by J. M. Pettit and M. M. McWhorter

Published (1961) by McGraw-Hill Book Co., Inc., 330 W. 42 St., New York 36, N. Y. 319 pages+5 index pages+xiii pages. Illus. 6¼+9¼. $9.75.

Amplification is an important function required in almost every electronic system. This volume contains much useful information concerning the principles and practice of electronic amplifier design, and thus should be of considerable interest to the electronics profession.

The book is concerned with low-pass and band-pass amplifier circuits using vacuum tubes and transistors. The treatment of the low-pass amplifier is particularly valuable. Attention is directed successively to steady state gain and phase characteristics at both low and high frequency limits of amplification, rise time and overshoot considerations, transient response effects associated with limitations in low frequency amplification, and additive amplification. The treatment of the band-pass amplifier is limited to a consideration of the steady state gain characteristic, including its relation to pole-zero configurations and the realization by circuit forms such as stagger tuning and double-tuned interstage coupling. Also included are an interpretation of the amplifier transfer function in terms of physical analogies (electrostatic, conduction, and membrane), a discussion of the use of conformal mapping in amplifier design, and a treatment of the common approximations to ideal gain and phase characteristics (maximal flatness magnitude, equal ripple magnitude, and linear phase). The ten chapters in which the generalities and specifics of low-pass and band-pass amplification are discussed are preceded by one chapter on models of active devices and followed by three chapters dealing with amplifier noise and amplifier measurements.

To this reviewer the book is attractive from several standpoints. The style of writing is the lucid, entertaining treatment which is found in Dr. Pettit's other books and technical papers. The illustrative examples and exercises at the end of the chapters seem most noteworthy, and in general, the selection of topics is excellent. The chapter on measurements is particularly valuable because of the contribution made in bridging the gap between amplifier theory and the practical achievement of desired response characteristics. It seems unfortunate, however, that the authors did not continue throughout the volume the relative emphasis given to transistor circuits in the discussion of conventional low-pass amplifiers. A single paragraph and footnote constitute the treatment of transistors in the chapter on additive amplification, and virtually no consideration is given to transistor band-pass amplifiers. Another serious omission is a substantive treatment of feedback in both vacuum tube and transistor amplifiers. Although one chapter is devoted to the feedback pair, the material discussed there could well have been treated elsewhere as an illustrative example or left as an exercise for the student. The importance of feedback, particularly in transistor circuits, warrants much more attention than is provided.

The book is probably best suited for use as a text in first year graduate electronics courses. It could also be used with profit in the senior year of a curriculum having a particularly strong electronics sequence. Because of its technical content and style of presentation, this book should be of great value as a textbook as well as a useful reference for practicing engineers. In writing this volume, the authors have made a significant contribution to the literature dealing with electronic amplifier circuits.

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New York, N. Y.

Writing for Engineering and Science, by Tyler G. Hicks

Published (1961) by McGraw-Hill Book Co., Inc., 330 W. 42 St., New York 36, N. Y. 275 pages+6 index pages+x pages+5 bibliography pages+exercises and examples. Illus. 6⅛×9⅛. $7.50.

This most recent book by Tyler Hicks attempts to provide basic help for all types of technical writers—students, practicing engineers and scientists, and professional writers in the technical fields. It is broad in scope, covering such various forms of writing as reports, articles, papers, instruction bulletins, military manuals, industrial specifications, and technical news and sales writing Recently published examples of the various forms are analyzed, and specific exercises are suggested to help develop writing skill and ingenuity.

The first five chapters of the book cover methods or techniques which are applicable to all forms of writing—outlines, grammar, usage, illustrations, and tables. A detailed "checklist" outlines a step-by-step procedure for the preparation of any major written assignment. Also included is a summary of important rules of grammar and usage, as well as a listing of examples of technical spelling and compounding, typical product names and proprietary terms, abbreviations, and common terms used in the publishing field.

The most useful part of the book for many engineers and writers may well be Chapter 5—Illustrations and Tables. This 34-page chapter discusses the advantages and disadvantages of various types of illustrations and tables, and gives the specific requirements for obtaining clear, legible, effective masters for publication and for lantern slides. The detailed treatment, the many excellent examples of "right" and "wrong," and the useful checklist at the end of the chapter should be helpful and valuable even to experienced technical writers.

Another chapter which should be of special interest to practicing engineers and scientists is Chapter 10—Effective Presentation of Technical Papers. This brief 8-page discussion presents eleven important pointers for speakers to ensure successful transmission of ideas to the audience. Observance of these rules by all engineers could do much to make technical conversations more enjoyable for all participants in the future.

If the book has a fault, it results from the attempt to be all things to all types of writers. The field of "engineering and science writing" is so broad today that its various forms cannot be covered thoroughly in separate chapters ranging from seven to twenty-five pages in length. This drawback is particularly apparent in the general section at the front of the book; although the examples given may be of interest to beginners in the field, the listings are so incomplete that most writers will still need such reference material as a good technical dictionary, a grammar book, a standard for abbreviations, and an index to product trade names. And if they have the complete reference sources, they may question their need for such an abbreviated treatment.

Because of its comprehensive scope, however, the book should contain something of value for all technical writers. And, because it is itself an example of good technical writing, reading it will prove pleasant and profitable.

E. M. McELWEE
Radio Corporation of America
Harrison, N. J.

A Methodology for Systems Engineering, by Arthur D. Hall

Published (1962) by D. Van Nostrand Co., Inc., 120 Alexander St., Princeton, N. J. 466 pages+12 index pages+xviii pages+references by chapter. Illus. 6×9¼. $12.00.

The author of this book is head of the Broad-band System Studies Department of the Bell Telephone Laboratories. The book itself is an outgrowth of a course given in the Communications Development Training Program of Bell Telephone Laboratories. One might jump from these facts to the conclusion that the book would be narrowly specialized to the problems of electronic communication systems. He would be quite wrong—the approach is a great deal more basic and broad. Like any good author, Mr. Hall begins by defining his subject, devoting the entire first chapter to this. The reviewer is in complete accord with the statement—"Systems engineering probably is not amenable to a clear, sharp, one-sentence definition." Nevertheless for a review one must be attempted. Systems engineering then deals with any and all affairs of the real world including deciding what to do and how to do it, planning and overseeing the execution of the project, and wrapping up the final loose ends. It thus subsumes much of the area of management and entails searching consideration of the true meaning and interrelationships of concepts such as value, feasibility, cost, etc.

The author wisely chooses to keep a specific concrete example as the focus of the wide-ranging abstract discussions, using for this purpose the development of the TD-2 microwave radio relay system. As an indication of how wide-ranging one may list some of the chapter headings: "Environmental Research," "Needs Research," "Partitions of the Field of Decision Making," "The Role of Measurement," "The Economic Theory of Value," "The Psychological Theory of Value," "Statistical Decision Making and Games," "The Casuistic Theory of Value," "The Language of Systems Structure—Graphical Models," "Input-Output and Functional Design," and "Psychological Aspects of Synthesis."

The author makes it plain that no book can teach the whole subject of decision making. What it can do, however, is to present the studied opinions of thoughtful decision makers as to what factors or disciplines have or might have had an influence on decisions they have made. A section of the preface seems worth quoting:

> "The book may be helpful to the specialist engineer beginning to undertake broader responsibilities. Management people in research and development organizations, either military or commercial, may find useful ideas and viewpoints that may be helpful in creating the kind of environment conducive to good systems engineering. Finally, since planning is a major theme, the book has relevance to planners in any field. It is only fair to warn the experienced practitioner of systems engineering that the ideas introduced and the examples illustrating them are often below the level of sophistication required for the solution of actual technical problems."

This reviewer is of the opinion that the book is indeed helpful in this spirit and can be read with profit by anyone seeking an understanding of the processes of technical management.

S. N. Van Voorhis
Washington, D. C.

Programming for Digital Computers, by J. F. Davison

Published (1962) by Gordon and Breach Science Publishers, Inc., 150 Fifth Ave., New York 11, N. Y. 174 pages+xi pages. Illus. 5¾×8⅝. $6.00.

This book offers an authoritative and well-written introduction to digital computer programming. It is intended for persons with no previous experience in programming, and presupposes no special knowledge of either mathematics or digital computer techniques. The presentation of topics is orderly, from the concept of programming, through elementary programming, through elementary programming techniques, to more sophisticated programming techniques such as interpretive and symbolic coding. A hypothetical computer is used to illustrate the exposition. The book is eminently readable and deceptively thorough in its treatment of the subject.

William C. McGee
Thompson Ramo Wooldridge Inc.,
RW Division
Canoga Park, Calif.

Advances in Computers, Vol. 2, Franz L. Alt, Ed.

Published (1961) by Academic Press Inc., 111 Fifth Ave., New York 3, N. Y. 421 pages+12 index pages+xiii pages+references by chapter. Illus. 6×9¼. $14.00.

This is the second volume in what, from all present indications, will be an outstanding series of annual volumes in advances in computer theory. This reviewer had the pleasure of being given the assignment of reviewing the first volume of this series, which set a high standard for the subsequent volumes. The second volume easily meets this high standard. The distinguishing features of a series such as this are aptly described by Alt in the preface. First of all it provides information on a wide range of subjects. Secondly it provides solid technical writing intended to be intelligible and interesting to specialists engaged in other fields. Finally it provides articles of a length long enough to introduce a newcomer to the field in a fairly respectable manner. In this reviewer's opinion the co-authors of this volume have succeeded admirably in achieving these goals in the subjects covered in this second volume.

These subjects include: "A Survey of Numerical Methods for Parabolic Differential Equations," J. Douglas; "Advances in Orthonormalizing Computation," P. J. Davis and P. Rabinowitz; "Micro-electronics Using Electron-Beam-Activated Machining Techniques," K. R. Shoulders; "Recent Developments in Linear Programming," S. I. Gass; and "The Theory of Automata, A Survey," R. McNaughton.

Considering first the contribution by Douglas this reviewer found his treatment surprisingly comprehensive and at the same time quite lucid in spite of the fact that a total of fifty-four pages, including a fairly good bibliography, were involved. The contribution by Davis and Rabinowitz was similarly good and is sure to be valuable to research workers in a variety of fields including system optimization theory. The bibliography in this case is particularly comprehensive. The contribution by Shoulders on Microelectronics deals with a specific and in Shoulders' opinion most promising approach to the problem, *viz.*, electron beam activated maching techniques. One might question this feature arguing that a broader treatment of the various approaches is in order particularly in light of the fact that it will be years before we can really feel that we are close to the ideal suggested by Dr. P. B. Myers in his status paper on the subject published in the 1961 WJCC Proceedings. In any event the case for Shoulders' approach is a good one and this reviewer finds no serious argument with it. The contribution by Gass on linear programming was also quite comprehensive and very well written with a fairly extensive bibliography. The concluding section by McNaughton on automata theory is largely a qualitative survey of the subject in contrast with most of the other contributions in this book. This is understandable in view of the vast and rapidly expanding nature of this most fascinating field. McNaughton's survey is nevertheless very complete.

The matter of the subjects selected for this second volume might be questioned. For example, it might have been most timely to present a contribution on sequential switching circuit synthesis techniques. This reviewer has no particular disagreement with the subjects selected for this volume all things considered, including certain practical matters pointed out by Alt in the Preface. In summary, this reviewer recommends this book highly to people in the computer and other pertinent fields.

Cornelius T. Leondes
University of California
Los Angeles, Calif.

Electromagnetic Waves, Rudolph E. Langer, Ed.

Published (1962) by The University of Wisconsin Press, 430 Sterling Court, Madison 6, Wis. 389 pages +xii pages+6 index pages+references by chapter. Illus. 6¼×9½. $6.00.

The book constitutes the proceedings of a symposium on applied electromagnetic theory conducted by the Mathematical Research Center, U. S. Army, at the University of Wisconsin. All of the papers were invited and deal with problems of current interest. The coverage is demonstrated best by listing the contributors and their papers:

"Electromagnetic Theory and Geometrical Optics," M. Kline; "Fields Excited in a Receiving-Type Antenna," F. J. Tischer; "The Pulse Solution Connected with the Sommerfeld Problem for a Dipole in the Interface between Two Dielectrics," H. Bremmer; "The Mathematical Foundations of Diffraction Theory," C. H. Wilcox; "Function-theoretic Aspects of Diffraction Theory," A. E. Heins; "Abstract Operator Methods in Electromagnetic Diffraction," N. Marcuvitz; "Diffraction by Polygonal Cylinders," J. Keller; "A Mathematical Model for Diffraction by Convex Surfaces," N. Logan and K. S. Yee; "The Quasi-Static Radar Cross Section of Complex Bodies of Radiation (Revolution)," K. M. Siegel; "Dipoles in Dissipative Media," R. W. P. King; "The Propagation of Electromagnetic Waves along the Earth's Surface," J. R. Wait; "Far Field Amplitudes and Inverse Diffraction Theory," S. N. Karp; "Propagation in a Non-Homogeneous Medium," B. Friedman; "Some Characteristics of Electromagnetic Wave Beams," G. Goubau; "Integral Equation Perturbation Methods in Low-Frequency Diffraction," B. Noble; and "Scattering of Waves by Two Objects," V. Twersky.

In the main, the papers are concerned with mathematical methodology rather than physical theory in accordance with the expressed purpose of the symposium. Diffraction problems, that is, the exterior electromagnetic boundary value problems, command most of the attention. The range of new results from the point of view of an applied physicist or an engineer is very limited but many procedures developed previously by these and other workers in a somewhat heuristic manner are put into proper mathematical form in these papers and are validated with mathematical rigor. There are concessions made to the relevance of the subject to physical problems—the papers do contain figures.

The theoretical or analytically oriented engineer will find the book very useful as a consolidation of a rather extensive literature into a set of intensive summaries and treatments of basic problems. With but a few exceptions there is little in these papers that lends itself to direct use by experimentalists and practical engineers. This is pointed out not as an adverse criticism of the symposium but as a matter of fact. For the purpose to which the symposium was directed the contributions are highly commendable and the volume forms a valuable addition to the theoretical literature in the field of classical electromagnetic wave theory.

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Your Future in Electronic Engineering, by Sol Levine

Published (1961) by Popular Library, Inc., 355 Lexington Avenue, New York 17, N. Y. 119 pages +4 bibliography pages +26 appendix pages. $4\frac{1}{4} \times 7$. \$.50.

This booklet covers many topics valuable to a young person who is interested in learning professional career possibilities in electronics. A comparison between electronics and electrical engineering is attempted, and the history of electronics is traced in a way which makes it meaningful. The personal qualifications and required aptitudes of a future electronic engineer are considered, as well as academic requirements for his high school preparation. Considerable assurance is given that potential college students can afford college, and information is provided in the area of the selection of a college and the admission to engineering colleges.

In the appendix are listed the ECPD accredited colleges, samples of the college board tests, and a selected list of bibliographies which provide knowledge of scholarships and more information about careers.

The potential electronic student is shown the opportunities and the kind of careers for electronic engineers and how to find jobs in electronic engineering. This is followed by current information on the earnings of electrical engineers and comparisons of their earnings with other scientific personnel.

A short section is included which states the situation regarding the employment of women in electronic engineering. Interesting case histories are shown of individuals who have succeeded in the field of electronics.

The final section is a statement of the growth of electronics and the future professional possibilities theoreof in the electronic industry which is predicted to grow to the largest of all businesses in the United States within the next ten years.

The book seems to be written for a high school senior and would also be of considerable value for counselors in high school and for freshman counselors in the schools of engineering in which guidance help is given to students in directing selection of their career. This book is an outstanding example of an honest approach to the subject. It is not high pressure, selling one on the advantages of electronic engineering over other subjects, but one which honestly deals with facts and provides information for potential students and those entering into the field. It is a book which will need to be updated periodically in order that current facts and figures are provided.

In the main, this book is recommended reading for questioning students and for those who have a definite interest in the counseling and guidance of students in electronic engineering career information.

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Classical Electrodynamics, by John D. Jackson

Published (1962) by John Wiley and Sons, Inc., 440 Park Ave. S., New York 16, N. Y. 610 pages +xvii pages +17 index pages +3 bibliography pages +11 appendix pages +references and problems by chapter. Illus. $6 \times 9\frac{1}{4}$. \$13.00.

This is an excellent book to use for a general two semester course in electromagnetics and electrodynamics for beginning physics or electrical engineering graduate students. These students by the time they begin a course such as this, will have met the method of separation of variables, but will most likely not have had enough experience with this or other mathematical methods appropriate to solving the boundary value problems which arise in electromagnetics, to solve any but the simplest problems. Secondly, the student probably will be ignorant of broad areas in electrodynamics which are currently subjects of considerable active interest and research in diverse fields such as high-energy nuclear physics, radio propagation and reception in plasmas, the generation of solar and galactic noise received by radio astronomers, etc.

The first part of this book will materially improve, to a useful level, the student's knowledge of the classical material he has covered as an undergraduate, particularly methods to solve problems. It should be mentioned that the student will certainly not learn of many useful tools and methods from this book; he will not have heard, for example, of tensor Green's functions (although he will have handled many vector problems), or of optical methods based on Fermat's principle or its extensions. This is not necessarily adverse criticism since there is a tremendous amount of equally important material in the book and naturally choices of what to include had to be made.

Much of the basic knowledge used in specialized fields, such as those listed above, is then supplied in the second half of the book. This half introduces special relativity and covariance concepts, then uses these to study relativistic particle kinematics and dynamics; motion in uniform and non uniform electric and magnetic fields, collisions between charged particles, radiation, absorption and scattering. An extensive chapter is devoted to magnetohydrodynamics and plasma physics treated macroscopially. In addition, wave propagation in a tenuous plasma and application to ionospheric propagation is treated as part of a chapter on plane electromagnetic waves.

Each chapter is well supplied with non trivial and interesting problems which extend the material presented in the text proper.

This book will inevitably be compared with Panofsky and Phillips which covers, in a more compact way, pretty much the same general material and requires about the same level of maturity. Jackson's book will probably be easier for a student to use, precisely because it is not so concise, and because, on the whole, more attention is given to presenting motivation.

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The Wave-Guide Mode Theory of Wave Propagation, by K. G. Budden

Publisher (1962) by Prentice-Hall, Inc., Englewood Cliffs, N. J. 293 pages +x pages +12 index pages +8 bibliography pages +12 appendix pages. Illus. $6 \times 8\frac{3}{4}$. \$16.00.

In the preface it is stated that the book is based on a course of lectures dealing with the normal mode theory of underwater sound. The main objective was to apply some of the methods that had been fruitful in study of the propagation of very-low frequency radio waves to great distances. The idea for the treatment originated at the Symposium on the Propagation of Very-Low Frequency Electromagnetic Waves held in Boulder, Colo., Jan., 1957. Some of these papers were published in the June 1957 issue of the Proceedings of the IRE.

The author's stated objective was to "set out" the mathematical theory as fully as possible. The emphasis is on the understanding of the mathematical methods rather than on their immediate practical use.

In the introduction of the book, the concept of an inhomogeneous plane wave is described in considerable detail. Such waves, which have complex direction cosines, dominate the whole of mode theory of guided wave propagation. In this context, both electromagnetic and sound waves are considered. This is followed by a lucid exposition of the theory for waveguides with perfectly reflecting walls. Chapters 4 and 5 show how to find the amplitude of a given mode excited by a given source. Both time-harmonic and transient sources are considered. His description of a VLF transmitter is rather quaint—"a bundle or network of wires connected by a down lead to transmitter whose terminal is connected to earth."

Chapter 6 deals with waveguides whose walls are parallel and sharply bounded. This includes a penetrating discussion of Fresnel reflection coefficients for complex angles of incidence.

In Chapter 7 the reflection from continuously stratified walls is considered. Again, the emphasis is on the physical understandings of the methods.

In Chapter 8 the reader comes to grips with the subject matter. The condition for a self-consistent mode is developed for a waveguide bounded by imperfectly reflecting walls. For example, if the reflection coefficients are $R_0(\theta)$ and $R_i(\theta)$ at the planes $z=0$ and $z=h$, respectively, the "fundamental equation of mode theory" is

$$R_g(\theta)R_i(\theta) \exp(-2ikh \sin\theta) = 1 = \exp(-2\pi in)$$

where θ is the (complex) angle of incidence at either boundary, k is the wave number and n is an integer. The discrete values of θ which satisfy this equation are the waveguide modes.

The author discusses this equation by using an analogy with a diffraction grating. One grating is above the ground and the other is below the ground. In each, the sources are of unequal strength and become weaker as one goes farther away from the ground. By analogy with an ordinary grating, it is inferred that contributions from adjacent lines of a grating must agree in both amplitude and phase. This gives the mode condition mentioned above. The conventional modes of positive order are formed by the combination of an inhomogeneous plane wave traveling upwards from the bottom grating and an inhomogeneous plane wave traveling downward from the top grating. Since the energy in the distant parts of the guide come predominantly from the remote and weaker images, the mode is attenuated.

The arguments now become slightly obscure. Modes, which the author describes as negative order, are introduced. They are attributed to the inhomogeneous waves travelling *downward* from the bottom grating and travelling *upward* from the upper grating. The characteristics of the spectra are obtained by inserting negative values for n in the above equation. This may be confusing to some since the mode equation is also satisfied by $\theta = -\theta_n$ when n is replaced by $-n$. However, these latter roots which are merely skew images of the positive order modes are not what Budden means by negative order modes. In fact, his negative order modes are improper as they lie on a wrong (or unused) Riemann sheet. Outside the guide they do not satisfy the Sommerfeld radiation conditions. Furthermore, such modes do not appear in the residue series representation of the field as shown by the reviewer.[1] While this fact is now recognized by Budden he sees fit to discuss their properties in some detail. He shows that they can be used as part of an alternative representation of the usually neglected, but not ignored, branch line integral. For the VLF problem, this is not a particularly convenient form.

The remaining chapters of the book are noncontroversial. They deal in turn with: sound waves in water with sharply bounded bottom, modes in a stratified system, surface waves[2] and earth curvature effects. Much use is made of the phase integral method of Eckersley and its extensions.

The book should serve as an excellent introduction to those comparatively new to the subject. It could also be used as a reference book to experienced workers. The bibliography is fairly extensive and is representative of the field up to about mid-1960.

(*N.B.* The curves of attenuation vs frequency shown in Figs. 9.8 and 9.9, on pages 144 and 145, appear to be in error. For example, at 20 kc the attenuation rate for the second mode in Fig. 9.8 (b) is of the order of 50 db.1000 km which is about ten times too high. Furthermore, it is not consistent with the author's own data shown in Fig. 9.7, on page 143.)

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Radiation and Waves in Plasmas, Morton Mitchner, Ed.

Published (1961) by Stanford University Press, Stanford, Calif. 156 pages+vi pages. Illus. $6\frac{1}{4} \times 9\frac{1}{4}$. $4.50.

This book is the fifth in a series resulting from talks presented at the Lockheed Symposia on Magnetohydrodynamics. The editor in his preface points out that the general topic of the fifth symposium "was selected so as to focus attention on the subjects of radiation and waves in plasmas, since these phenomena are necessarily inherent to all processes involving the interaction of a conducting gas and a magnetic field."

The seven papers and their authors, are: "Kinetic Equations for Plasma and Radiation," A. Simon (18 pages); "Static Equilibria, Stability, and Wave Propagation in Symmetrical Collisionless Plasmas," I. B. Bernstein (35 pages); "The Electron-Stream Model of a Plasma, and the Problem of Energy Conservation in Landau Damping," O. Buneman (28 pages); "Microwave Emission from Ultra-Energetic Plasmas," D. B. Beard (21 pages); "Survey of Some Coherent Wave Propagation Properties of Plasmas," J. E. Drummond; "Thermal Generation of Fully Ionized Cesium Plasma," G. S. Kino (19 pages); and "Experiments on Alfven-Wave Propagation," J. M. Wilcox, A. W. DeSilva, W. S. Cooper III, and F. I. Boley (19 pages).

The first five papers are essentially theoretical, and the last two, principally experimental. Simon discusses the systematic approximation schemes for arriving at the Vlasov and Fokker-Planck equations and sketches the Simon and Harris generalization of the expansion method necessary to handle the general case of plasma and radiation. Bernstein examines the self-consistent steady states of plasmas by the method of constants of particle motion, and he applies the results of the analysis to a discussion of slab equilibria, nonlinear electrostatic waves, and to cylindrical Langmuir probes. Buneman considers a plasma model consisting of a superposition of a large number of interpenetrating streams of electrons. He shows that solving the equations of continuity and motion for all the streams is tantamount to solving the collisionless Boltzmann equation and shows how energy conservation relates to Landau damping. In the fourth paper Beard discusses the problem of calculating the emission of cyclotron radiation from high energy magnetoplasmas, and presents some numerical results on radiation loss. J. E. Drummond examines some of the properties of plasmas in the case where statistical fluctuations can be ignored and presents a criterion for energy exchange between the plasma and radiation. In terms of this criterion he discusses the effect of interaction of electron beams in a finite plasma, electron-cyclotron resonance, electron-ion wave interaction resonance, radiative coupling produced by a spheroidal obstacle in a plasma, and the maximizing of power transfer of radiation to a plasma.

In the sixth paper, G. S. Kino describes the experiments, and the underlying theory, of the generation of a highly ionized cesium plasma by the method of resonance ionization at high work-function surfaces. He then goes on to discuss experiments on the interaction of an electron beam with a cesium plasma. The last paper presents results of experiments on hydromagnetic waves including how measurements of density and temperature derived through these experiments compare with the same quantities derived through the theory of Stark broadening of hydrogen lines.

Some of the basic material discussed in the book has appeared in the literature. Some of the papers presented here can be considered as extensions of the published work. There is a considerable part that is new. Like the others of this series, this book is a valuable addition to the library of people interested in the physics of plasmas.

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RECENT BOOKS

Headquarters Staff of the American Radio Relay League, *The Radio Amateur's Handbook.* The American Radio Relay League, Inc., West Hartford, Conn. $3.50.

Parker, R. J. and Studders, R. J., *Permanent Magnets and Their Application.* John Wiley and Sons, Inc., 440 Park Ave. S., New York 16, N. Y. $16.00.

Swalin, R. A., *Thermodynamics of Solids.* John Wiley and Sons, Inc., 440 Park Ave. S., New York 16, N. Y. $12.50.

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[1] J. R. Wait, *Geofisica Pura applicata*, vol. 37, pp. 103–115; 1957.

[2] In the chapter on surface waves and in the index, reference is made to "Beveridge antenna." This should be spelled Beverage after its inventor Dr. H. H. Beverage.

Abstracts of IRE Transactions

The following issues of Transactions have recently been published, and are now available from The Institute of Radio Engineers, Inc., 1 East 79 Street, New York 21, N. Y., at the following prices. The contents of each issue and, where available, abstracts of technical papers are given below.

Sponsoring Group	Publication	IRE Members	Libraries and Colleges	Non-Members
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Aerospace and Navigational Electronics

Vol. ANE-9, No. 1, March, 1962

NAECON Luncheon Address—Major Gen. D. C. Doubleday (p. 3)

A New Guiding and Tracking System—H. P. Kalmus (p. 7)

A new application of the near-field theory is described which permits determination of the relative bearing of one object with respect to another by a simple phase measurement without an additional reference signal. The same instrument is used to measure distance between the objects. The angle indication is independent of distance.

Airborne Doppler Radar Navigation of Jet Transport Aircraft—R. N. White (p. 11)

Trans World Airlines will pioneer use of Doppler radar as a primary means of transport aircraft navigation over the North Atlantic. This paper summarizes flight test results using dual Doppler radar sensors and dual Doppler navigation computers on Boeing 707 long range aircraft. Test flights have been flown over TWA's North Atlantic routes for almost two years to "prove-in" the Doppler system.

Criterion for Angular Noise in Star-Lock Systems—E. K. Sandeman (p. 21)

This paper shows that, if the signal-to-noise power ratio (S/N is found for any steady deviation δ of a parameter from its required value, then in a closed-loop linear servo system, the actual rms variation of the parameter from its required value due to noise cannot exceed the rms value:

$$\sigma = (S/N)^{-1/2}$$

The quantity σ may then be used as a criterion of noise in the servo system.

FM Star-Lock System Using Mask with Linear Sectors—E. K. Sandeman (p. 24)

This is a known type of system in which a suitable rotating element in the optical system causes the image of the star field to nuate over the surface of a mask divided into alternative sectors of opaque and transparent material.

When the lock star is on the axis of the entry optical system, the lock-star image traverses a circular path on the mask concentric with the mask giving rise to an unvarying frequency in the output of a photo cell behind the mask.

With misalignment of the star image from the axis of the entrance optical system, the circular track is displaced as the result of which the output of the photo cell is frequency modulated. The resulting FM wave is suitably processed to provide misalignment signals along two axes.

This paper derives the value of

$$\sigma = (r/R)(S/N)^{-1/2}$$

for the system, using various photomultiplier tubes used as photo cells, and various parameters such as angular velocity of star image, number of sectors on mask, and diameter of objective of entrance optical systems:

r = radial displacement of star-image track.
R = radius of star-image track.

FM Star-Lock System Using Mask with Spiral Sectors—E. K. Sandeman (p. 35)

This system is identical with the FM system using a linear mask except that the sectors of the mask are bounded by spirals.

The value of

$$\sigma = (r/R)(S/N)^{-1/2}$$

is derived for the case of spiral masks of three kinds.

Abstracts (p. 48)
PGANE News (p. 49)
Contributors (p. 50)

Broadcasting

Vol. BC-8, No. 1, April, 1962

Experience with American Klystrons in Recent European UHF-TV Transmission Systems—G. M. W. Badger (p. 2)

The author presents data on the use of American-built power klystrons as high-gain linear amplifiers in Europe's recently opened UHF-TV spectrum. More than 30 transmitters have been constructed there, using these tubes. Color is a central element in the UHF application. This is the first newly-designed TV transmitter apparatus to use klystrons in ten years. Much development has taken place, and the European experience indicates that new capabilities and different considerations now apply to the use of this type of microwave amplifier in TV transmission. Some of these are developed by the author.

Telechrome-JVC 2-Head Video Tape Recorder—J. R. Popkin (p. 14)

The Telechrome-JVC 2-Head Video Tape Recorder is quite unusual and different when it is compared to other VTR's. It has a number of features not found in any other video tape system of recording. Some of these are as follows: 1) Ability to obtain pictures with the tape running slowly, standing still, or even running in reverse for obtaining special effects. 2) Ability to simultaneously record, monitor, and playback while recording, allowing optimum recording adjustments to be made while recording and also, at the same time, being able to make sure the picture is "in the can." 3) There is inherently no horizontal banding, scalloping, skewing, or venetian blinding of the pictures because of the recording method used. 4) Because of the design philosophy, first cost as well as maintenance costs are drastically lower than transverse type head recorders; lower priced individually replaceable heads, lower tape costs, simpler circuitry as well as a processing amplifier not being required. 5) The great ease in obtaining still frame pictures allows precise editing to be done.

Standards for Stereophonic Broadcasting—H. L. Kassens (p. 24)

Reduction of Bandwidth in Television Transmission Systems—A. L. Buck (p. 29)

A problem which urgently needs solving is that of the tremendous waste in bandwidth created by our present nonstatistical analog system of television transmission. Attempting to reduce bandwidth while maintaining the same channel capacity is seen to yield poor results.

The most effective attacks on the problem have been by using digital coding systems which take advantage of picture redundancy and certain properties of the human eye. Several of these systems, using various combinations of pulse code modulation, delta modulation, and run-length coding, are briefly discussed.

Letters to the Editor (p. 34)

Circuit Theory

Vol. CT-9, No. 1, March, 1962

Nonlinear Distortion in Feedback Amplifiers—C. A. Desoer (p. 2)

Consider a feedback amplifier F with a nonlinear output device T_0 and an open-loop amplifier A having the same gain and the same output device T_0. If the gains of the forward amplifier μ and feedback network β are independent of frequency, it is well known that under the usual conditions the nonlinear distortion ζ of F due to T_0 is related to the nonlinear distortion $\hat{\zeta}$ of A by $\zeta=\hat{\zeta}/1+\mu\beta)$. In this paper conditions are determined under which a similar formula, namely $\zeta=(1+\mu\beta)^{-1*}$, applies when μ and β are strictly stable linear time-invariant amplifiers. The interpretation of the formula is the following: ζ is the function of time which is output of an amplifier whose gain is $1/(1+\mu\beta)$ when $\hat{\zeta}$ is its input, and $\hat{\zeta}$ is the nonlinear distortion of the open-loop amplifier A.

Steady Oscillations of Parametric Subharmonic Oscillator—N. Rouche (p. 7)

Parametric subharmonic oscillators are already used as elementary circuits for digital computers. It is shown that a theory exists, which, by purely algebraic procedures, gives a reasonable account of the steady-stage oscillations of these systems. The concepts used belong to linear circuit theory.

The stability is studied for each solution, by treating small perturbations also by linear methods. This is possible with a good approximation only in case the circuit is sufficiently selective. A few diagrams are drawn to show the agreement between the theoretical model considered here and actual circuits studied by others.

Some Aspects of Perturbational Analysis of Time-Varying Circuits—J. Lenkowski (p. 13)

A method of iterative analysis of a wide class of time-varying networks is considered. The unknown steady-state node voltage (mesh currents) are obtained in the form of infinite series, the convergence of which is investigated. Formally the method is suitable for analyzing nonselective time-variable networks.

The Selection of Circuit Components for Optimum Circuit Reproducibility—P. W. Broome and F. G. Young (p. 18)

This paper describes a method by which the values of the components in a network may be specified so that the properties of the network will conform closely to prespecified design target values. The analysis is applicable to the design of networks in which the desired parameters can be expressed by algebraic equations. Two problems are solved to illustrate the method.

Conditions for Network-Element-Value Solvability—R. S. Berkowitz (p. 24)

The concept of network-element-value solvability is introduced and its importance in the establishment of methods of automatic trouble-shooting of electronic equipment is pointed out. First, a set of definitions is given which enables an objective discussion to be made of network solvability of arbitrary passive, linear, lumped parameter networks with respect to a restricted set of external terminals (available and partly available). Next, a relation is obtained connecting the number of available and partly available terminals of a network with the number of admittance functions determining the measurable behavior of the network. Theorems A, B and C then give solvability conditions for purely resistive networks. It is shown that the theory developed can be extended to include networks with internal energy sources (Theorem D). A general necessary condition for network-element-value solvability is then obtained (Theorems E and F). Finally, examples are given showing applications and limitations of the theorems obtained.

Stability and Power-Grain Invariants of Linear Twoports—J. M. Rollett (p. 29)

It is shown that the stability of a linear twoport is invariant under arbitrary lossless terminations, under interchange of input and output, and under "immittance substitution," a transformation group involving the arbitrary interchanging of impedance and admittance formulations at both ports. The quantity

$$k = \frac{2\gamma e(\gamma_{11})\gamma e(\gamma_{22}) - Re(\gamma_{12}\gamma_{21})}{|\gamma_{12}\gamma_{21}|}$$

(where the $\boldsymbol{\gamma}$ may be any of the conventional immittance z, y, or hybrid h, g matrix parameters) is the simplest invariant under these transformations, and describes uniquely the degree of stability, provided $Re(\gamma_{11})$, $Re(\gamma_{22}) \geq 0$; the larger k is, the greater the stability and in particular $k=1$ defines the boundary between unconditional and conditional stability. The quantity k is thus the basic invariant stability factor. Its definition is also extended to include the effect of terminating immittances, which may be padding resistances or source and load immittances, or both.

Certain power-grain functions, including the maximum available power gain, are shown to be invariant under immittance substituion, and k is identified as a function of ratios between them, where they exist. This provides a fundamental way of determining k, apart from calculating it from matrix parameters, and indicates that it is a measure of an inherent physical property.

Cascaded Active Twoports—R. A. Johnson (p. 33)

If a number of identical twoport networks (active or passive) are cascaded, the input impedance to the cascade will usually approach one of the iterative impedances of the twoport no matter what termination is used. In the passive-termination passive-twoport case, this will be the passive iterative impedance which is unique provided the other iterative impedance is active. In the passive twoport cases, where there are two passive iterative impedances or an active termination, and in the active case, simple conditions are established for the existence and nonexistence of a limit and the limit identified. It is shown that the unique limiting value of the imput-impedance sequence is the iterative impedance at which the derivative of the twoport impedance transformation assumes a magnitude less than unity.

Secondary results include a closed form for the input impedance of the general twoport cascade, the proof of nonexistence (except in a single special case) of periodic fluctuations in input impedance as sections are added, and the proof that the derivatives of the transformation evaluated at the two fixed points are mutually inverse. Examples of both passive and active networks are presented and the rate of convergence indicated.

Sensitivity Minimization in Active RC Synthesis—D. A. Calahan (p. 38)

Since the majority of active RC synthesis techniques are based upon the partitioning of network functions into subnetwork functions, it was though to be of interest to discover how this decomposition might be achieved to minimize sensitivity to the active element. This is, then, an extension of the work of Horowitz, Sipress, and others.

Two types of active decompositions were considered: RC-NIC and RC-RL. It was shown that, *regardless of the degree of the polynomial decomposed*, when RC-RL decomposition is possible at all an RC-RL decomposition can be found which results in a lower zero (pole) sensitivity figure than any RC-NIC decomposition. In the process of obtaining this result, the form of the RC-RL decomposition(s) which minimize(s) zero sensitivity is obtained. It is shown that, in general, there are an infinite number of these RC-RL decompositions with the same minimum sensitivities at all zeros (poles). This is in contrast to the Horowitz decomposition, which uniquely minimizes sensitivity in the RC-NIC case.

Cascade Synthesis of Two-Element-Kind Networks—J. D. Schoeffler (p. 43)

Realization of a two-element-kind network in the form of a cascade connection of subnetworks, each of which places in evidence one or more sets of transmission zeros, is discussed. A new technique for achieving this realization based on the use of an intermediate three-element-kind network is presented. The use of zero shifting in order to arrive at subnetworks which are realizable in unbalanced form without mutual coupling is outlined.

Cascade Synthesis of Nonreciprocal Lossless 2-Ports—W. L. Rubin and H. J. Carlin (p. 48)

Necessary and sufficient conditions for the synthesis of nonreciprocal lossless n-port are shown also to be necessary and sufficient for the realization of a nonreciprocal lossless 2-port as a cascade of reciprocal and nonreciprocal lossless 2-ports. Nonreciprocal transmission zeros are realized by four canonic nonreciprocal 2-ports, which are analogous to the Darlington A, B, C, D networks that are required for realization of reciprocal transmission zeros.

Cascade Driving-Point-Impedance Synthesis by Removal of Sections Containing Arbitrary Constants—J. B. Murdoch and D. Hazony (p. 56)

Through extensions of Richards' theorem it is shown that certain realizable network sections containing one or more arbitrary constants may always be removed from an RLC driving-point-impedance function leaving, as a termination, another RLC driving-point-impedance function which contains the same arbitrary constants. These constants are utilized to produce desired characteristics in either the removed network section or the terminating impedance.

Some of the removed sections contain a gyrator which, it is shown, may always be eliminated through proper choice of some of the arbitrary constants to yield other purely reactive reciprocal sections which still contain at least one arbitrary constant.

The constants may also be chosen to reduce the rank of the terminating impedance. The result is a perfectly general reciprocal cascade-synthesis procedure applicable to any prf driving-point impedance.

Specific impedance operators (associated with the removed sections) and their synthesis by Darlington-type procedures are considered in detail.

Synthesis of Radio-Communication Nets—S. S. Yau (p. 62)

A radio-communication net is a communication network in which links between stations have unlimited capacity to transmit information. Such a network can be represented by a graph with weights on the vertices which correspond to the capacities of individual stations. The capacity of a radio-communication net of n stations is described by a matrix of order n called a terminal-capacity matrix. A necessary and sufficient condition for a matrix to be realizable as the terminal-capacity matrix of a radio-communication net is found. A simple algorithm for synthesizing a radio-communication net of a given terminal-capacity matrix, which is proved to have minimum sum of vertex capacities and minimum number of branches, is obtained. A theorem concerning all possible structures of a radio-communication net with the same terminal-capacity matrix is established.

Synthesis of Resistive N-Port Networks with N+1 Nodes—C. C. Halkias, I. Cederbaum, and W. H. Kim (p. 69)

In this paper a systematic procedure is proposed to obtain the n-port structure appropriate to the Y matrix of a resistive network containing exactly $n+1$ nodes. The method presents:

> A set of necessary conditions which may eliminate quickly a large class of matrices from further consideration for realization; A simple procedure for the determination of a port structure in the case the Y matrix contains a few or no zero elements; A realization procedure which is particularly convenient in case the Y matrix contains a large number of zero elements. This pro-

cedure is also extended to the realization of Z matrices.

It is shown that sometimes there exists more than one network with $n+1$ nodes realizing a given matrix Y with different port structures.

An evident application of the method presented in this paper is the realization of fundamental circuit matrices and fundamental cut-set matrices of oriented graphs.

Controllability in Linear Sequential Networks—M. Cohn (p. 74)

A linear sequential network (LSN) with m inputs and n delay elements can be viewed both as a linear control system and as a sequential machine. A linear system is k controllable if and only if every state transition can be achieved in exactly k steps. It is shown that controllability is equivalent to n controllability, and that a LSN is n controllable if and only if it is a strongly-connected sequential machine. Techniques are given for determining controllability in LSN's, for finding a sequence of n input vectors for an arbitrary state transition, and for finding a similar sequence of k input vectors, where k is the smallest integer such that the LSN is k controllable.

The Visualization of Frequency-Modulation Transients by Means of Mechanical Models—M. J. E. Golay (p. 78)

It has long been known that electrical circuits have equivalent mechanical circuits, and that the correspondence between the two can be established in two ways, namely, either voltage⇄force, current⇄velocity, capacitance ⇄compliance, etc., or voltage⇄velocity, current⇄force, capacitance⇄mass, etc.

If, however, one searches for a mechanical model which preserves the elegance and strength of Argand's vectorial diagram, in which voltage at or near the center frequency of a band-pass circuit can be represented by stationary or slowly rotating phasors, the classical equivalent mechanical circuits are inadequate, and a new form of equivalence must be adopted.

This article describes this new equivalence which is obtained, for a large class of important circuits, by dropping Kirchhoff's laws and utilizing Thevenin's theorem, so that the mechanical models so established give a correct and easily visualized representation of input and output voltages; albeit intermediate points in the electrical circuits do not correspond generally to intermediate points in the mechanical model.

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Education

Vol. E-5, No. 1, March, 1962

Editorial—W. R. LePage (p. 1)

A PCM Experiment for the Senior Electronic Laboratory—R. C. Mackey (p. 2)

An experiment on pulse-code modulation designed for the senior-year electronics student is described. PCM is pedagogically desirable for its embodiment of a wide variety of pulse and digital techniques. The experiment draws upon the component-type experiences typical of undergraduate courses and integrates them into a complex system study. Emphasis is on functional interaction rather than on how a particular circuit accomplishes its function. Sixteen level quantization is used with provision for injection of noise and variation of system parameters.

An Instructional Servomechanism Laboratory—J. R. Ward (p. 6)

This article describes a laboratory servomechanism and an associated laboratory sequence which were designed to complement theoretical first courses in servomechanisms at either senior-year undergraduate or first-year graduate level.

The primary aims were to provide the student with the means for an experimental verification of theoretical results and, at the same time, to encourage him to establish some feeling for the physical reality of an operating feedback system.

On the Pedagogy of Feedback Systems—L. D. Harris (p. 10)

The undergraduate student contacts feedback ideas from two distinct points of view, each with its own nomenclature and symbolism: electronics on one hand, and control systems on the other.

In the typical electronics or communications book treating feedback at an undergraduate level, the analysis is constrained to the steady-state sinusoidal situation. Nyquist's criterion is merely presented without proof or justification. The student finds this theorem, when presented so briefly, a rather mysterious and vague concept.

On the other hand, the author of the control systems or servomechanism text gives space in his book for a more thorough treatment of the feedback system but usually he uses terms and symbols that to the student seem to be unrelated to those terms and symbols used in the electronics "brand" of feedback.

In recent years, the pole-zero concept has become a part of the undergraduate student's background in circuits. Pedagogically, the root-locus approach to the feedback system follows with ease. In contrast, Nyquist's criterion definitely becomes the more difficult concept. Furthermore, the root-locus approach is broader in scope.

From three to fifteen lectures are needed to bridge the gap between the pole-zero concepts of circuits to a basic understanding of the feedback system.

Switching-Type Servosystems in an Elementary Undergraduate Curriculum—Z. H. Meiksin (p. 12)

The paper discusses how the concept of switching-type servosystems can be introduced into an undergaduate curriculum without requiring a more advanced background in mathematics on the part of the student than is ordinarily expected. A differential equation approach is used to study the response of a second-order system which is excited with a step function input. The system starts to respond in a linear mode of operation with an over-all positive feedback and switches into a different linear mode with an over-all negative feedback at a predetermined instant. The system is designed so as to respond with no overshoot. The response time is shorter than that of a conventional critically-damped linear negative feedback system with the same major physical components. The results of a rigorous study by means of a phase-space representation are also given.

Control System Digital Computer Transfer Function Simulation—J. J. Jonsson (p. 15)

The z transform of simple delay, integrator, leadlag, and differentiator networks are suggested as the basic building blocks for simulating complex control systems on a digital computer. The system parameters retain their explicit identity, thus facilitating analysis and design of the system as a function of specific parameter changes.

A Unified Procedure for Deriving the Differential Equations of Electrical and Mechanical Systems—G. W. Ogar and J. J. D'Azzo (p. 18)

Based on energy considerations, it is possible to obtain the differential equations of motion of any physical system. A statement of equilibrium involving operations on energy functions is the Lagrange equation

$$\frac{d}{dt}\left(\frac{\partial T}{\partial q_n}\right) - \frac{\partial T}{\partial q_n} + \frac{\partial D}{\partial q_n} + \frac{\partial V}{\partial q_n} = Q_n.$$

Providing that the kinetic energy T, potential energy V, and dissipation function D can be written, the differential equations of the system are obtained by following a straightforward systematic procedure. It is not necessary to employ Kirchhoff's laws or Newton's force law to obtain the equations of electrical and mechanical systems. Rather, the two kinds of systems fall within the scope of this general method. The energy method is particularly useful in dealing with electromechanical systems and with mechanical systems that combine rotation and translation. Nonlinear as well as linear systems can be handled with equal ease.

Versatility of the method is shown by its application to various examples, chosen in more or less increasing order of complexity. A set of tables is provided, listing the energy functions for each basic type of electrical, mechanical and electromechanical element. Those charged with teaching students the different disciplines of dynamics and electric circuits should find herein a common meeting ground wherein one general method suffices to yield the necessary differential equations.

A New Approach to Fourier Coefficient Evaluation—C. F. Chen (p. 27)

A new method for determining the coefficients of the Fourier series is given. This method is developed by considering each sample as a vector. The two coefficients a_n and b_n are obtained simultaneously. Compared with the present techniques, this method is much simpler and more accurate. Illustrative examples are included.

Teaching Machines: General Purpose and Special Purpose—S. L. Levine and W. J. Knight (p. 30)

The main purpose of this paper is to present and clarify the subdivision of teaching machines into the General Purpose and Special Purpose categories.

Initial defining of: Teaching Machines, General Purpose Teaching Machines, Special Purpose Teaching Machines, and Teaching Machine Technology will establish a frame of reference within which this paper will be presented. The distinctions between the general purpose and special purpose teaching machines will be in the areas of the motivations of each type, the differences in the basic functional block diagrams, if any, and the applications of each type to technical training and engineering education. A prediction is also given.

Evolution of Graduate Education in Electrical Engineering in Metropolitan Areas—A. B. Giordano (p. 32)

The evolution of graduate education in electrical engineering began in the early 1890's and progressed at a rapid pace in the 1920's, particularly in metropolitan areas conscious of community needs. In these areas, evening programs held the spotlight because of the ever-demanding need to provide graduate engineers with advanced knowledge. Such cooperation between community interests and colleges has resulted in a wide variety of patterns of part-time study on campus and, more recently, off campus. The later development is viewed with criticism in several educational circles although off-campus programs are filling tremendous requirements arising from industrial concentrations not within easy reach of a university or college. The evolution seems to indicate that off campus programs are not a passing fancy and that such requirements are very likely to be best satisfied in the long run by the establishment of graduate centers with a faculty in residence. As an example, the Polytechnic Graduate Center on Long Island is described. (The Center, actually located in Farmingdale, N.Y., began its operation on September 25, 1961, with a graduate student body of nearly 700 in day and evening programs involving advanced courses in Aerospace Engineering, Electrical Engineering, Electrophysics, Mathematics, Mechanical Engineering, Physics, and Industrial Management. Close to 150-part-time day students are attending on a released-time basis, in addition to 45 full-time students in residence.)

Panel Discussion on Graduate Electrical Engineering Education—R. L. McFarlan (p. 37)

Contemporary Thinking Regarding Graduate Electrical Engineering Education—J. R. Whinnery (p. 38)

Role of Industry in Graduate Electrical Engineering Education—S. W. Herwald (p. 41)

Future Trends and Problems in Graduate Electrical Engineering Education—E. Weber (p. 44)

Summary of Education Session AIEE 1961 Winter Meeting—K. B. McEachron (p. 47)

Electron Devices

VOL. ED-9, NO. 2, MARCH, 1962

Accurate Noise Measurements on Transistors—E. R. Chenette and A. Van Der Ziel (p. 123)

This paper is concerned with a method of noise measurement which permits improved accuracy by circumventing some of the problems of the usual comparison techniques. Results are presented of measurements of I_{eq} and R_n showing good agreement between theory and experiment. It is suggested that noise measurements may be a very satisfactory method of determining the effective base resistance for inhomogeneous structures. The theoretical representation of the noise sources, including the effect of generation-recombination in the emitter-base region, is summarized in the appendix.

"Second Breakdown" in Transistors—H. A. Schafft and J. C. French (p. 129)

"Second breakdown" in transistors has been characterized as an abrupt reduction in V_{CE}, at a collector current designated by I_M, when the transistor is swept through its V_{CE} vs I_C characteristics. A critical review of the literature concerning this phenomenon and a more complete description of its characteristics are given. It appears that "second breakdown" is a more fundamental property of the transistor than has previously been thought. Each of the mechanisms thus far considered in the literature, in particular the "pinch-in" effect and *p-n-p-n* action, has been examined and found inadequate. The apparent dependence of the initiation of the phenomenon on the quantity of energy absorbed, and on the ambient temperature, indicates that it may be related to some thermal mechanism. This points to the importance of examining "second breakdown" in terms of energy dissipated rather than in terms of voltage or current as has been done to date.

Minority Carrier Injection Characteristics of the Diffused Emitter Junction—D. P. Kennedy and P. C. Murley (p. 136)

For the double-diffused transistor, a one-dimensional analysis is presented on the minority carrier injection properties of a diffused emitter junction. This junction is bounded on one side by a reverse biased collector and on the other by an ohmic contact of arbitrary recombination velocity. Furthermore, arbitrary magnitudes of minority carrier lifetime are assumed in both the emitter and base regions of this semiconductor device.

Injection efficiency characteristics are graphically illustrated throughout a wide range of physical and geometrical parameters. Assuming for example, variations in the emitter junction depth, injection properties are demonstrated for transistors exhibiting a fixed collector location and also for transistors exhibiting a fixed base width. A comparison is also shown between the calculated minority carrier injection from this analysis and from other, more approximate methods.

Abrupt Junction Diode Theory—D. P. Lieb, B. D. Jackson, and C. D. Root (p. 143)

Forward voltage-current characteristics for planar abrupt junction silicon and germanium diodes are presented. These curves, derived directly from the basic current and continuity equations, extend the knowledge of diode behavior from the low injection region continuously to the high injection region. They include the effects of conductivity modulation, ohmic drop, and electric fields in the base, but neglect space charge recombination currents. The presentation includes treatment of both infinite recombination and majority carrier base contacts. Band pictures for several cases are shown and discussed in terms of the various mechanisms influencing them.

An Analysis and Experimental Investigation of the Binistor—P. W. Ross and J. G. Skalnik (p. 153)

This article is an analysis of a four-layer semiconductor device known as the binistor. An approximate equivalent of this device may be constructed from suitably connected *NPN* and *PNP* transistors. Analysis of the equivalent circuit configuration by means of the small-signal hybrid parameters enables a prediction of the circuit characteristics. From this analysis, it is shown that the device exhibits a voltage-stable negative-resistance characteristic in contrast with the usual current-stable negative resistance obtained from circuits employing a four-layer semiconductor device.

This analysis indicates the manner in which the negative-resistance portion of the collector current-voltage characteristic is dependent upon the small-signal parameters of the *NPN* and *PNP* transistors and upon a certain resistance external to the device.

A linear model of the device is proposed. Use of the model allows a prediction, within experimental accuracy, of the switching characteristics of the binistor used as a bistable device. Switching between the two states may be accomplished by three methods of control.

This model suggests that the transfer characteristic between two particular ports should have the hysteresis characteristics of a mechanical relay. This analysis is born out by experiment.

A circuit formed by a series combination of two binistors is shown. This circuit has two stable states with a stable output either at essentially the supply voltage, or at approximately ground potential. A modification with an intermediate stable state is also obtainable with the proper bias conditions.

A logical extension of the binistor structure to a device that may have any desired number of stable states is proposed and a circuit of this type with three stable states is shown and discussed.

Because of certain internal interaction phenomena, the device may be used as a modulator, and an experimental modulator circuit is developed and investigated.

High-Frequency Base-Transport Factor and Transit Time of Graded-Base Transistors—S. Mayburg and B. Smith (p. 161)

Closed expressions are derived for the modulus and argument, as well as for the real and imaginary parts of the complex base-transport factor (β) of diffusion and uniform drift-field transistors. Since these expressions involve only trigonometric, exponential, and hyperbolic functions, they are suitable for straightforward numerical computation as well as theoretical analysis. The variation of computed β-cutoff parameters as a function of impurity concentration is illustrated graphically and shown to be in good agreement with an approximate relation between the β-cutoff frequency and transit time due to Moll and Ross.

A Theory of Transistor Cutoff Frequency (f_T) Falloff at High Current Densities—C. T. Kirk, Jr. (p. 164)

It is shown that the observed falloff in the f_T of a transistor at high currents is due to the spreading of the neutral base layer into the collector region of the device at high current densities. The base layer spreading mechanism derives from an analysis of the effect of the current-dependent buildup of the mobile-carrier space-charge density in the collector transition layer. Calculations show that at sufficiently high collector current levels, the mobile space-charge density in the collector transition layer cannot be considered negligible in comparison to the fixed charge density of that region. The over-all effect of taking the mobile space charge into account in analyzing the collector transition region is that, at high current densities, the transition region boundary adjacent to the neutral base layer is displaced toward the collector metal contact with increasing collector current. The attendant widening of the neutral base layer results in the observed, high-current falloff in f_T.

The application of this theory to transistor structures of both the alloy and mesa variety yields, in each case, calculated curves of f_T vs I_C which are in reasonably good agreement with experiment.

Reverse Transient Characteristics of a P-N Junction Diode Due to Minority Carrier Storage—D. P. Kennedy (p. 174)

Analysis of the transient switching characteristics of a *p-n* junction diode is considered a boundary value problem; solution of this problem yields mathematical equations applicable to the design of high-speed computer components. This analytical technique is used to establish the transient current of a semiconductor diode when an external biasing potential is rapidly switched from the forward to the reverse direction. Using a one-dimensional model of finite geometry, minority-carrier storage is assumed within a region of arbitrary lifetime, bounded on one side by the junction and on the other side by an ohmic contact of arbitrary recombination velocity. Further, this region of carrier storage is assumed to contain a drift field of constant magnitude as would result from an exponential type of conductivity grading.

Mathematical equations are presented which characterize this transient situation from its initiation until the junction current has decayed to some arbitrary magnitude. Applications of this analysis are illustrated in graphical form throughout a range of parameters characterizing practical semiconductor devices.

Switching Response of Graded-Base *PN* Junction Diodes—S. Y. Muto and S. Wang (p. 183)

This paper extends the earlier analysis by Kingston of the switching response of a uniform-base diode to a graded-base diode. It concerns the time required to switch a diode from a forward-biased to a reverse-biased condition. The current transient can be separated into two phases: 1) the constant current phase during which the carrier density at the junction changes gradually from a forward-biased to a reverse-biased condition, and 2) the nonconstant current phase during which the injected carriers stored in the base region gradually disappear. In the present analysis, it is found that in a graded-base diode where the impurity concentration decreases from the emitter junction towards the base contact, the time for the constant current phase is greatly shortened because of favorable initial carrier distribution. The effect is already significant if the impurity concentration changes by a factor from 3 to 1 from the emitter junction to the base contact. To shorten the nonconstant current phase, however, a much larger change of impurity concentration, say of the order from 500 to 1, from the emitter junction to the base contact is needed.

Design of Periodic Electromagnets—S. W. Maley and Byrne (p. 188)

The use of periodic permanent-magnet focusing structures in TWT research is complicated by the difficulty of changing the level of flux density on the axis. It is necessary to completely disassemble the focusing structure and remagnetize each individual magnet. To overcome this difficulty, periodic electromagnets have come into use. Using electromagnets in place of permanent magnets, the flux density on the axis can be changed simply by varying the magnet current.

The construction techniques for such magnets are discussed and formulas are given for finding the necessary ampere turns in the windings.

The Analysis of Residual Gas in Electron Tubes—H. B. Frost (p. 190)

A method has been devised for analysis of the residual gas content of small tetrodes or pentodes. In contrast to other methods which have been reported, the gas content of the tube being studied is not changed markedly by the analysis; analyses may be made repeatedly as the tube is operated, and moderately low pressures (1×10^{-10} mm Hg) and small quantities (10^{-9} cc mm) can be detected.

A 90-degree sector magnetic analyzer with a 3-cm radius of curvature and 30-mil slits (resolution 1:20) is sealed to the tube to be analyzed prior to pumping. The analyzer is made of Corning 0120 glass with a conductive lining. The tube being tested serves as an ion source, avoiding the complications of a second hot filament. The device has been calibrated by comparison with known gases on a vacuum station.

This method has been applied to study the gas content of the M1941 experimental pentode intended for applications which require extreme life and reliability. The normal gas pressure in this tube, after trolley pumping and 100 hours aging, is about 1×10^{-9} mm Hg, predominantly He, H_2, and CO. When no getters are used, the partial pressures of H_2 and CO are higher, perhaps 1×10^{-8} mm Hg. When titanium-alloy anodes are used in tubes without getters, the partial pressure of hydrogen is much higher, up to 1×10^{-6} mm Hg. A number of these tubes have been followed for over 10,000 hours.

Concurrent studies of the cathode emission have shown it to be markedly influenced by small partial pressures of hydrogen when pure nickel cathode cores are used. Hydrogen is very effective in raising the emission, but the emission falls quickly as the hydrogen pressure is reduced. At least part of the improved cathode performance observed in tubes with titanium anodes must be attributed to the increased hydrogen pressure which accompanies the use of titanium anodes. These data on hydrogen with pure nickel should not be extrapolated arbitrarily to active cathodes.

About Scan Magnification of TV Picture Tubes—E. Gundert and J. Lotsch (p. 197)

In a television receiver the horizontal deflection is of critical importance because of the high deflection power. Recently, various proposals have been published, according to which the electron beam is to be deflected over a small angle only, in order to diminish the deflection power. Subsequently this small deflection angle is to be increased by an electrostatic or magnetic lens. In the present paper, it is shown with the aid of general laws of electron optics that such a scan magnification by an electrostatic or magnetic lens necessarily causes a decrease of the resolution, and thereby, of the quality of the television picture, unless known possibilities of increasing the resolution are employed simultaneously. The calculation also firms that with magnetic deflection, unlike electrostatic deflection, post-acceleration does not lead to a significant reduction in deflection power with unchanged resolution.

Waveguide-Vane Coupled Slow-Wave Structure Suitable for a High-Power Traveling-Wave Amplifier—J. W. Gewartowski (p. 204)

A class of slow-wave structures, previously proposed for use in the magnetron amplifier, is examined in the linear version for application in a high-power, traveling-wave amplifier. Two versions are studied, both theoretically and experimentally, with particular emphasis on the frequency range suitable for wide-band, high-voltage application.

Fundamental Interaction Impedance of a Helix Surrounded by a Dielectric and a Metal Shield—B. J. McMurtry (p. 210)

The fundamental interaction impedance for a helix surrounded by a dielectric medium and a conducting shield is computed and the result is found to be in good agreement with measurements on several TWT structures. Results obtained in this paper indicate that the addition of a conducting shield around a helix reduces the interaction impedance; this impedance reduction becomes more severe as the shield is brought closer to the helix, and as γa, the ratio of helix circumference to guide wavelength, is made smaller.

A sheath helix surrounded by a dielectric medium and a conducting shield is used to obtain a factor representing the impedance reduction caused by the shield. This impedance reduction factor is then combined with Tien's factors to compute the helix impedance.

The Effect of Helix Loss on Noise Figure in Traveling-Wave Tubes—B. P. Israelsen (p. 217)

Helix loss increases the noise figure of a TWT by altering the amplifying properties of the tube, and also by acting as a source of thermal noise which is amplified by interaction with the beam.

Noise power originating in the helix propagates as a wave and undergoes amplification in the same manner as the signal. This noise power adds to the noise figure of the tube by an amount proportional to the attenuation of the helix and to its temperature, and inversely proportional to the tube gain per unit length.

The effect of refrigerating the helix has been demonstrated by several experiments in which low-noise TWT's were immersed in liquid nitrogen while monitoring the noise figure. The reduction in noise figure varied from a few tenths to nearly one db. One case of particular interest is that of a WJ-226 low-noise TWT, operating in the frequency band 1.4 to 2.3 Gc, which showed a minimum noise figure of 2.6 db when operating in a room temperature environment. On cooling the tube to liquid nitrogen temperature, a minimum noise figure of 1.7 db was obtained, at a frequency of 1.65 Gc.

Analysis of a New Crossed-Field Amplifier, The "Eal," or Electromagnetic Amplifying Lens—W. C. Brown and G. E. Dombroski (p. 221)

A new form of crossed-field microwaves and millimeter wave amplifier which combines an interaction process that results in axial gain with a quasi-optical handling of the RF input and output power is described. Because of its functional similarity to a microwave lens and the additional property of amplification, it is called the Electromagnetic Amplifying Lens. Its advantages are outlined, and its interaction mechanism considered in detail. It is shown that the voltage gain is a linear function of distance in the useful operating range. When the RF level is low, interference between forward- and backward-traveling waves on the waveguide results in loss of control on the space charge. This phenomenon limits the gain available with stable device operation; useful gain of at least 20 db is theoretically possible with a bandwidth of several per cent. The crossed-field interaction principle that is employed assures efficiences of better than 50 per cent.

A Broad-Band Slow-Wave Structure for a Millimeter Traveling-Wave Tube Amplifier—J. Hirano (p. 228)

A new filter-type slow-wave structure, which is considered as an interdigital line loaded with inductance in shunt, is described in this paper.

The results of the cold-test study of the structure are presented in terms of the phase velocity and impedance measurements. For the structure studied, interaction takes place between multiple electron streams and the axial electric field of the +1 space harmonic.

The circuit has broad-band properties of phase and interaction impedance as a circuit for a traveling-wave amplifier. The maximum deviation of the phase velocity for a 30 per cent bandwidth has a value on the order of ±0.3 per cent. The structure is suitable for use as a high-power amplifier operating with a 20 per cent bandwidth in the millimeter-wave region.

Gridded Electron Guns for High Average Power—H. E. Gallagher (p. 234)

The design and performance of electron guns producing high-average-power beams which are controlled by an intercepting-type grid are described. The design consists of a modification of the design of Pierce-type electron guns to allow for the effect of grid insertion, and calculation of the amplification factors based on the potential distribution. The performance is evaluated in terms of the beam shapes and average beam powers obtainable.

Measured amplification factors are compared with calculated values. Factors influencing the measured beam shapes are discussed. Trajectories of electrons emitted as secondaries from the grid and those of electrons deflected by the lens effect of the grid wires were plotted using an analog computer and electrolytic tank. The shapes and focusing properties of electron beams from similar gridded and nongridded guns are compared.

Expressions relating the average beam power capability to the gun and grid dimensons are developed. The calculated average beam power capabilities are compared with measured values. Average beam power as high as 8 kw has been obtained with electron guns of a size suitable for use in X-band twt's.

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Announcement (p. 246)

Electronic Computers

Vol. EC-11, No. 1, February, 1962

Ten Years of Computer Simulation—J. McLeod (p. 2)

The past and present of computer simulation are examined, and on that basis some predictions for the future are made.

Deploring the analog vs digital concept fostered by some, the author stresses the complementary aspects of the two methods. Then, drawing heavily on the experience of others as well as his own, the more important improvements in simulation techniques and equipment of the past ten years are discussed.

The two approaches to analog-digital simulation—the hybrid-computer in which both techniques are combined in one machine, and the combined-simulation in which relatively pure analog and digital computers are connected to operate together—are both viewed as attempts to capitalize on the unique advantages inherent in each method, and as presenting common problems.

The requirement for better education, not only of the potential user—the scientist, the engineer, and the researcher in other fields such as biology and medicine—but of the undergraduate and the public, is found to be the greatest need.

Improved equipment having greater reliability—for somewhat less money—is also needed. But it is predicted that that will come. It is the need for education which demands the attention of all who are interested in the future of computer simulation.

Operational Amplifiers Using Controlled Superconductors—P. M. Chirlian and V. A. Marsocci (p. 6)

The use of controlled superconductors in analog-computer circuitry is discussed. It is shown that the operations of summation, multiplication by a constant, differentiation, integration, and multiplication of two variables may be performed by these circuits. It is pointed out that the advantages of compactness, reliability, and light weight that are inherent to the use of controlled superconductors are now obtainable for analog as well as for digital equipment.

A Comparison of Higher-Order Difference Methods in the Solution of Beam-Vibration Problems—D. T. Greenwood (p. 9)

Several higher-order difference methods are investigated and compared for the problem of finding the natural frequencies of the lateral vibration of a beam. All of the methods considered are applicable to either digital or analog computers, although particular reference is made to the analog computer.

The methods considered in most detail use the same basic central difference approximation, the variations occurring in the method of representing boundary conditions. Three higher-order approaches to the problem of boundary conditions are presented. They are 1) the use of one-sided differences of fourth order, 2) the use of symmetry assumptions, and 3) the passive-circuit approach. Each method is shown to have its advantages, the final choice depending upon the particular requirements of the problem.

Results are presented in the form of curves of percentage mode-frequency error vs number of cells for the various approximation methods.

Simulation of a Biological System on an Analog Computer—E. C. DeLand (p. 17)

The purpose of this paper is to discuss a method for the construction of a mathematical model of a large biological system. This method, based on Gibbs' free energy hypothesis, uses the format of mathematical programming, while the actual computation is accomplished by the method of steepest descent. The biological system chosen to exemplify the mathematical method was the respiratory function of the blood in the human lung. This method is based on the postulate that chemical mixtures tend toward a reaction equilibrium which minimizes the potential, or free energy, of the system. We may thus write down the classical Gibbs free energy function for each chemical species, and require that total free energy relative to some standard state be minimized under the conditions of the experiment. The solution of the equilibrium problem consists of a set of mole numbers which minimizes the free energy function, subject to equations for conservation of mass and non-negativity.

The analog computer solution of the respiration model was undertaken not only to give fast, sensitive tests of the mathematical model and its assumptions, but also to obtain a simulation of the time dependent system. Examples of the mechanization of the equations are presented in this paper, and also results are computed for the static equilibrium of a canonical model.

An Infinite-Resolution Function Genetator—P. H. Wendland and P. M. Hanlet (p. 26)

An electro-optical device is described which provides a continuously-variable dc electrical signal in response to a shaft rotation. The elimination of a mechanical contact provides low torque, long life, and high-speed operation. Shaping of the thin film resistance track associated with this device produces an interesting function generator. Data is presented for successful operation of the laboratory model. An analysis is provided of the requisite track shaping to produce arbitrary functions. The electrical equivalent circuit of the device is analyzed, and the conditions necessary for successful operation described.

Real-Time Analog-Digital Computation—M. E. Connelly (p. 31)

The relative advantages of analog and digital techniques in simulating complex, nonlinear systems in real-time are discussed. A hybrid configuration is suggested consisting of a basic digital computer and peripheral, high-speed analog elements used on a time-shared basis under the control of the digital program. Programs for function generation and for the solution of the aircraft roll equation are presented to illustrate the operation of the hybrid computer and the significant increase in the effective computing speed of the digital computer that results from the incorporation of peripheral analog elements. Further gains can be made by tailoring the order code and logic of the digital computer to the specific problem class of interest.

The hypothesis is presented that a hybrid computer is technically feasible today that would be competitive with analog techniques on the basis of both cost and the ability to simulate natural aircraft frequencies in real-time. Moreover, such a computer would offer substantial advantages with respect to accuracy, dynamic range, flexibility, size, power consumption, and reliability.

Parametric Techniques for Eliminating Division and Treating Singularities in Computer Solutions of Ordinary Differential Equations—A. Hausner (p. 42)

By using the analog-computer independent variable time, as a parameter, a differential equation can be transformed into a set of first-order equations containing no divisions. This makes it possible, by means of other mathematical transformations to prevent unbounded functions from occurring during a computation and sometimes to continue solutions through singularities. The discussion includes a detailed application of the method to a second-order differential equation containing both zero and infinite slopes in the solution. The graph of the solution is obtained without reprogramming and with less equipment than that required by usual techniques.

An Analog-Digital Real-Time Computer—T. D. Truitt (p. 46)

A new kind of digital computer employing analog computing techniques is introduced. Planned as the central calculator in a "faster-than-real-time" computing system for a space range, the computer employs many, high-speed, digital circuits in parallel to calculate the solutions to sets of nonlinear differential equations. Parallel computing equipment employing simple numerical algorithms are shown to be superior in speed and accuracy of solution of sets of many equations than a hypothetical system of an unlimited number of conventional, stored program computers operating in unison. The operating and programming methods are described as an outgrowth of existing analog and digital computer techniques. The applications described indicate the effectiveness of the computer in the role of a prediction and control computer for a missile and space range instrumentation system.

Simulation of Steam Generation in a Heat Exchanger—P. J. Hermann (p. 53)

An analog-computer flow chart is developed for use in setting up a simulation of the steam-generation process in a heat exchanger. It is assumed in the paper that the rate of heat flow from the primary side of the heat exchanger to the secondary side is already known. The technique described considers only the process in the secondary side of the heat exchanger. Factors such as variations in pressure, boiling-point temperature, induction water heat rate, heat of vaporization, specific volume of steam, and rate of secondary steam extraction are considered. Some simplifications are made *e.g.*, that the secondary steam is always at saturation conditions and that water level control in the boiler is good. Use is made of steam table data in function generators so that a fairly large range of operating conditions can be simulated.

Analog Computation of Green's Function for Integrating Tow-Point Boundary Value Problems—R. M. Terasaki (p. 57)

A method is described for the analog computation of the solution of linear two-point boundary value problems, *i.e.*, the problem of a linear ordinary differential equation with linear two-point boundary conditions. The nonhomogeneous problem, in particular, is considered; the differential equal for y on the real interval $0 \leqq x \leqq 1$ is taken to be nonhomogeneous. The method for its solution is based upon the integral formula for the solution, namely,

$$y(x) = \int_0^1 G(x, t) f(t) dt,$$

where $G(x,t)$ is the Green's function satisfying two-point boundary conditions while f is a known integrable function. The paper describes a method for finding a specific set of initial value problems whose solutions, taken in linear combination, form the Green's function whose second argument (t) is fixed. This technique reduces the two-point boundary value problem to a set of initial value types and makes the continuous computation of the Green's function as a function of x for fixed t amenable to analog means. The application of the described technique to the adjoint boundary value problem yields a means for continuous computation of G as a function of the second argument (t) for fixed values of the first argument (x). This is the required form for the analog evaluation of the integral formula.

The theoretical aspects of the method found are stated, after which an example of a simple non-self-adjoint problem from the study of structures is solved on an electronic analog computer.

The amount of equipment needed to compute the Green's function is commensurate with the amount required to compute the solution to the differential equation of the problem. Moreover, once the Green's function is found and set on a function generator, the system can be studied thereafter by utilizing the simple integral formula; only two function generators, a multiplier, and an integrator are then required.

Accuracy Improvements of the Tapped-Potentiometer Function Generators—N. Parezanovic and M. Dujmovic (p. 63)

This paper describes a procedure for correct calculation of the resitance of the potentiometer function generator, including the load resistance of the generator. The possibility of generating the function by taking inequidistant values of the independent variable is also described as is the possbility of generating some special functions.

Proposed IRE Standards for Analog Computers (p. 67)

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Engineering Management

Vol. EM-9, No. 1, March, 1962

About This Issue (p. 1)

Applied Business Research—W. A. Hahn, Jr. (p. 3)

An enterprise, financially oriented or otherwise, needs managers and management scientists. Persons with differing skills, attitudes, and incentive reward systems fulfill these two roles respectively. The manager is identified as a single individual and the management scientist as a team. The "traditional" approach of identifying the differences in the two classifications is presented. A method of selecting problems is described that appears to be meaningful to both the manager and management scientists and which serves as a basis for research portfolio selection. The usual scheme for allocating research effort between short- and long-range payoffs is analyzed. This single distribution of effort with little real time concontribution and little "way out work" creates a negative relationship situation, and generates comparatively low payoffs to the enterprise as well as to the managers and management scientists. A second, bi-modal scheme is outlined involving real time help to operating managers by management scientists, a significant "way out" contribution, and an area of cooperative work. This scheme seems to generate a positive atmosphere of mutual respect, interdependence, and cooperative action. This approach takes the same personal and professional differences as the first approach, but uses them to their mutual advantage rather than as points of conflict. An attempt is made to suggest a general hypothesis for cooperative team business research wherein the line manager is a participating member of the research group. The elements, characteristics, strength and weaknesses of management and the management sciences are detailed and these same categories are used as the bases of selection for the "best" from each classification to describe the integrated team of manager *plus* management scientists.

Utilization of "Normalized" Data for Defense Contracts—D. W. Kornreich (p. 11)

"Normalized curves" represent a means of evaluating the relationships of time, total expenditures, subcontract expenditures, and a number of activities and events. They represent data on previous contracts that have been categorized and reduced to common scales. "Normalized curves" can be used either to evaluate a summary of the detailed planning and progress on current contracts or to forecast the probable requirements and performance on anticipated contracts. Many of these calculations have been performed on a digital computer since March, 1960. "Normalized curves" have proven to be a valid analytical tool for predicting overruns, schedule slippages, and poor planning. Since the relationships of the values of time, resources, and milestones are based upon actual previous contracts, the acceptance of "normalized curves" has increased to the point where they are now being used in the preparation of proposals for new contracts.

Cost-Effectiveness as a Method of Evaluating Design Changes—J. P. Kornfeld (p. 15)

A procedure is outlined for utilizing cost-effectiveness as a measure of the economic feasibility of making design changes. The method is pertinent to those design changes with significant influence on performance and reliability of the weapon system, on over-all weapon system effectiveness, and on the total cost of the weapon system. Similarities exist between the evaluation of decisions in the area of weapon systems design and decision areas commonly encountered in the nonmilitary business world. The effect of alternative product designs on potential market penetration, production processes and profits, for example, could be described by either analytical techniques or simulated by "business gaming," or both.

A Method for Evaluation of Defensive Weapon Delivery Systems—M. R. Heembrock (p. 23)

A procedure is given for the application of a measure of value of radar and defensive weapon control systems. Value, as distinguished from performance, is defined herein as the sum of the weighted integrals of a system's cumulative probability of detection, per unit cost, with respect to detection range over an appropriate interval. The problem boundaries are established as the minimum required detection range and the maximum usable detection range, subject to a restriction on the minimum performance acceptable. An orderly array of such parameters as aspect angle, closing rate, target size, and scan limits is given as a spectrum of conditions of use. The result is a table of the value function which serves to relate what is needed from an electronic system to what is provided by the system. The method is illustrated in a specific example. By permitting a coherent treatment of the entire set of factors which characterize a system and the environment in which it operates, the procedure is a decision-making aid for rejection of systems which give inadequate performance and evaluation of those which are found adequate.

Research Orientations and Attitudes Toward Teamwork—N. W. Storer (p. 29)

Data was collected by questionnaire on the motivations and attitudes of 88 research workers in a major state agricultural station. The data tend to support these hypotheses: 1) the basic scientist will be more "deeply involved" in his work than the applied scientist; 2) he will demonstrate a greater allegiance to the social system of science; and 3) he will tend to view teamwork as acceptable only when his co-workers help to increase his enjoyment of the research. Some cautions are given by the author about the dangers of generalizing from this limited study to all situations involving teamwork in research.

Decision Making as It Affects Long-Range Planning—W. J. Stolze (p. 33)

An analysis is made, by means of a flow diagram, of the various steps in the evolution of a military contract with a private firm. A second flow diagram traces the decisions involved in the utilization of the scientific and engineering staff in a military electronics company. Several important decision areas in the firm are highlighted and related to long-range planning.

A Survey of the Intra-Company Impact of Weapon System Management—F. Kast and J. Rosenzweig (p. 37)

A survey was made on the internal organizational and administrative adjustments made by companies in the weapon systems business. A questionnaire was returned by more than 40 top executives and was followed up by interviews with 23. The effects of weapon system management on industry responsibility, skill requirements, acceleration of R + D and other factors are discussed.

About the Authors (p. 41)

Information Theory

Vol. IT-8, No. 3, April, 1962

On a Moment Theorem for Complex Gaussian Processes—I. S. Reed (p. 194)

A general theorem is provided for the moments of a complex Gaussian video process. This theorem is analogous to the well-known property of the multivariate normal distribution for real variables, which states that an nth order central product movement is zero if n is odd and is equal to a sum of products of covariances when n is even.

Filterless Approximations of Kth Order to Coherent Detection—I. S. Reed and P. Swerling (p. 196)

A class of procedures for detection of a pulsed signal having unknown frequency shift is described. From this class, procedures can be selected whose detection performance approximates that of coherent detection arbitrarily closely. Such procedures do not require the construction of a filter bank; on the other hand, they do not yield information as to the magnitude of the frequency shift of a detected signal. Envelope detection followed by video integration, and Reed's so-called semicoherent procedure are elements of this class of detection procedures.

An iterative method for obtaining successively better approximations to coherent detection is described, the implementation of which would require a large number of mixing and delay operations. The number of iterations required to insure any given degree of approximation to coherent detection, for any number of integrated pulses, is estimated.

Finally, the possible application of these ideas to reception of signals by array antennas is described.

Some Bounds for Error-Correcting Codes—L. D. Grey (p. 200)

This paper concerns itself with binary coding and more specifically with an upper bound for the number if binary code works of length n such that every two differ in at least d positions from each other. It is shown that there is a relationship between this problem and a well-known extremum problem. The techniques developed for the latter problem are used to derive upper bounds for the former, one of which has been obtained in an entirely different way by Plotkin. If $B(n,d)$ denotes the maximum number of binary code words of length n and distance d, it is shown that

$$B(n, d) \leq \frac{2d}{2d - n} \quad \text{for} \quad d > n/2$$

The second bound due to Rankin is

$$B(n, d) \leq \frac{8d(n - d)}{n - (n - 2d)^2} \qquad \text{for} \quad n - \sqrt{n} < 2d \leq n$$

provided the binary code words consists of pairs, each pair differing in all n positions. Although Rankin's bound contains the restriction that the binary code words consists of pairs, each pair differing in n positions, it is shown that the restriction may not be severe in the sense that the bound can often be attained.

A New Upper Bound for Error-Correcting Codes—S. M. Johnson (p. 203)

By refining Hamming's geometric sphere-packing model a new upper bound for nonsystematic binary error-correcting codes is found. Only combinatorial arguments are used.

Whereas Hamming's upper bound estimate for e-error-correcting codes involved a count of all points $\leq e$ Hamming distance from the set of code points, the model is extended here to include consideration of points which are $>e$ distance away from the code set. The percentage improvement from Hamming's bounds is sometimes quite sizable for cases of two or more errors to be corrected. The new bound improves on Wax's bounds in all but four of the cases he lists.

Sequential Decoding for Discrete Input Memoryless Channels—B. Reiffen (p. 208)

A scheme is described which sequentially encodes the output of a discrete letter source into the input symbols of a discrete input memoryless channel, with adjacent channel symbols mutually constrained over a length, n. The encoder permits desired channel input symbol probabilities to be approximated closely. Decoding at the receiver is accomplished with delay n by means of sequential tests on potential transmitted sequences with reject criteria set so that incorrect sequences are likely to be rejected at short lengths and the correct sequence is likely to be accepted. Averaged over a suitably defined ensemble of encoders, the decoding scheme has an average probability of error with an upper limit whose logarithm approaches $-nE(R)$ for large n. $E(R)$ is dependent only on the data rate R. For a channel symmetric at its output with equally likely inputs, the exponent $E(R)$ is optimum for rates greater than a rate called R_{crit}. For such symmetric channels, a computation cutoff rate R_{comp} is defined. For $R < R_{\text{comp}}$, the average number of decoding computations does not grow exponentially with n, but algebraically. R_{comp} is also defined for an asymetric channel. In this case too, the average number of decoding computations grows algebraically with n for $R<R_{\text{comp}}$.

Information Capacity of a Single Retinal Channel—D. H. Kelly (p. 221)

Recent psychophysical experiments with sinusoidally flickering waveforms provide suitable data for calculating the maximum rate at which information can enter the human visual system, according to the single-channel model which explains these data; *i.e.*, if the signal-to-noise ratio in the retinal pathways governs the minimum detectable modulation amplitude, then the latter is an appropriate measure of the maximum number of distinguishable signals with a given narrow frequency band. Applying the Hartley-Shannon Law, these measured (gain-vs-frequency) response curves are integrated to obtain the (retinal average) channel capacity. This procedure yields a monotonic function of the adapting luminance, increasing at high photopic levels to almost 800 bits per sec per channel or about 10^9 bits per sec for the entire retina. Most of this large *input* capacity is obviously not directly available for the transmission of (random) signals by the human observer; the results are discussed from this viewpoint and compared with other estimates of sensory information rates.

On the Problem of Time Jitter in Sampling—A. V. Balakrishnan (p. 226)

There are many communication as well as control systems—in fact, an increasing number of them—in which at some stage a continous data source is sampled "periodically," at the nominal rate of $2W$ samples a second, W being the highest frequency component of the data. There are, generally speaking, two kinds of errors introduced by the sampling mechanism: errors in amplitude and errors in timing, or "time jitter." This paper is concerned with the latter.

We assume a random model for the jitter. We begin with a study of the properties of the jittered samples for both deterministic and stochastic signals. Depending on the stochastic properties of the jitter, the presence of a discrete component in the signal may give rise to new discrete components as a result of jitter. Generally speaking, however, the effect of jitter is to produce a (frequency) selective attenuation as well as a uniform spectral density component. The more correlation in the jitter, the less the spectral distribution is affected.

Various measures of the "error" due to jitter are estimated. Thus the error may be the mean square in the fitted samples or some linear or nonlinear operation thereof. Also, weighted mean square errors are considered, and general methods of estimating these errors are developed.

The problem of optimal use of the jittered samples is next considered. Interpreting the optimality to be in the mean-square sense, an explicit solution for optimal linear operation is obtained. Also for a wide class of signals it is shown that jitter does not affect the nature of the optimal operations; linear operations for instance, remain linear, although with different weights.

To illustrate the methods an example drawn from telemetry is given, where the timing is derived from the zero crossing of sine wave and the time jitter is taken as due to noise. The jitter is highly correlated and the results involve some lengthy calculation.

Sequential Detection in Radar with Multiple Resolution Elements—M. B. Marcus and P. Swerling (p. 237)

In this paper the techniques of sequential analysis are applied to a multiple-resolution-element search radar for different types of detection. By using sequential methods such a radar shows considerable saving compared to fixed-scan-rate detection radars.

Many of the problems occurring in sequential radar detection are examined; the difficulties of obtaining analytical results for multiple-resolution-element sequential radars are discussed. Most of the results of this paper were obtained by simulation. Included are interesting results which suggest that truncation is not necessary for the tests which were considered.

Curves are given describing the improvement obtained by sequential detection procedures. The curves are discussed in detail to make this paper useful to those whose primary interest is in the results which are obtained.

Least-Square Synthesis of Radar Ambiquity Functions—S. M. Sussman (p. 246)

The synthesis of radar ambiguity functions is approached by minimizing the integrated square error between an arbitrary desired function and a realizable ambiguity function. The approximation is carried out via an orthonormal signal basis which generates an "induced basis" over the time-frequency plane consisting of all pair-wise cross-ambiguity functions of the signal basis. The minimum mean-square error and the corresponding signal are determined through an eigenvalue problem for 1) approximation by complex autoambiguity function and 2) approximation by complex cross-ambiguity function.

A new form of the realizability theorem shows that the conditions for cross-ambiguity functions differ from those for autoambiguity functions only in the absence of the symmetry condition: $F(\tau,\omega)=F^*(-\tau, \ -\omega)$. Moreover, the approximations by cross- and auto-ambiguity functions coincide whenever the desired function has the above symmetry.

When an ambiguity function realizable by a known signal is to be approximated on a finite basis, least-square approximation in signal space or in ambiguity-function space leads to equivalent results. The relation between the mean-square errors in the two spaces is obtained.

For the phase incoherent radar case an iteration procedure is presented for successively modifying the arbitrary phase assigned to the desired function. Convergence is proved in the sense that the error is nonincreasing at each state of the iteration, but arrival at the best approximation to the desired magnitude is not guaranteed.

As an aid in numerical applications, a formulation based on a discrete sample grid in the time-frequency plane is derived. With the appropriate grid dimensions, the analytic procedures carry over directly into sampled-data representation.

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Microwave Theory and Techniques

Vol. MTT-10, No. 2, March, 1962

A Microwave Ferrite Single-Sideband Modulator—A. Clavin (p. 98)

A microwave single-sideband modulator has been designed utilizing two reflection types of Faraday rotation ferrite-balanced modulators. Power is fed to the two balanced modulators by means of a 3-db quadrature hybrid such that each modulator has equal incident power with a 90-degree phase difference. The output power of the balanced modulators is combined by means of a magic tee sum and difference circuit. It is shown that if the modulation signals applied to the balanced modulators are in phase quadrature, the upper sideband will appear at the output sum arm and the lower sideband will appear in the output difference arm. An analysis of the device relates the spurious and undesired sidebands to the conversion loss, and a method is proposed for minimizing carrier output. The drive power is reduced due to the use of reflection-type balanced modulators, and experimental data is presented for the modulation frequency impedance and drive power requirements. The temperature and frequency sensitivity of the undesired sidebands have also been measured. A number of applications of the device are discussed.

A Nondegenerate Traveling-Wave Parametric Amplifier—K. P. Grabowski (p. 103)

The traveling-wave parametric amplifiers reported to date are not sufficiently competitive to ensure their use in advanced radar systems. The major hindrance is the relatively high-radar noise figure which is due to the fact that the signal and idler frequencies are about equal; *i.e.*, the amplifier is degenerate. Initial experiments directed toward obtaining a nondegenerate microwave traveling-wave parametric amplifier are reported in this paper. A promising circuit has been developed and an S-band nondegenerate amplifier has been built and tested. In the first part of the paper the circuit is described and the experimental results are given. The second part of the paper describes procedures which have proved useful in the development of the circuit and which should also prove useful in future investigations.

Line Width and Bandwidth of Millimeter-Wave Resonance Isolators—P. Vilmur and K. Ishii (p. 108)

A theoretical derivation is made of bandwidth as a function of resonant frequency of a single crystal ferrite resonance isolator at millimeter wavelengths. The derivation takes into account the ferrite isolator as a bounded system. Using the derived relation of bandwidth and resonant frequency, and Kittel's relation between resonant frequency and applied field, equations are derived which relate line width to resonant frequency, line width to the applied magnetic field, and line width to frequency bandwidth. These resulting equations are compared with experimental data obtained with a single crystal barium ferrite isolator from 58 to 59 kMc. The theoretical relations agreed closely with the experimental data within the accuracy of the measuring equipment at these frequencies. In general, the results showed that for small frequency ranges (1 kMc) bandwidth and line width increase almost linearly with frequency, bandwidth and line width are linearly related, and line width is a fairly complicated but increasing function of applied field.

Some Characteristics of Microwave Balanced Modulators—R. C. Mackey (p. 114)

Microwave modulator characteristics pertinent to two state balanced modulation are discussed. An equivalence between balanced modulation and phase modulation is shown for rectangular modulation waveforms and experimental results are described. The characteristics of a tuned hybrid tee, untuned hybrid tee and novel circulator type of balanced modulator are compared. *X*-band measurements show that a carrier rejection of 70 db and modulator loss of 3 db can be achieved with carrier levels up to several hundred milliwatts. The carrier rejection of an untuned modulator is dependent on crystal match and data showing dependence of the match on orientation and temperature are presented.

Symmetric Strip Transmission Line Tee Junction—A. G. Franco and A. A. Oliner

Several different network forms have been employed previously to characterize the symmetrical strip-line tee junction and the parameters of these networks have been obtained by various means. In this paper the available theoretical and experimental results are systematically correlated. A choice, based on design convenience, is made of the most appropriate network form, and recommendations are given for the values of each of the parameters in this representation. In some ranges, the available data were inadequate, and additional experimental results were taken in order to clarify the recommendations.

The Use of Exponential Transmission Lines in Microwave Components—C. P. Womack (p. 124)

This paper describes some techniques for utilizing exponential transmission lines in microwave components in order to reduce element lengths, and hence size and weight, and to significantly increase the operating frequency range. Formulas are developed which relate line length to the frequency and rate of taper for transmission line resonators, and a nomogram is included for easy determination of spurious frequencies. Additional formulas are given for the distributed representation of lumped elements using exponential sections of both coaxial and strip transmission line, and their use described in application to microwave filters and related components. In addition, the paper describes how unusually large rejection bandwidths can easily be obtained by proper selection of the individual element lengths and rates of taper.

Eigenvalues for a Centrally Loaded Circular Cylindrical Cavity—D. M. Bolle (p. 133)

The general availability of large high-speed computers has made the use of series expansions in complicated field theory problems feasible even when these series do not converge rapidly. This paper outlines the method and illustrates its application to the solution of a problem in cylindrical coordinates. At the same time, the errors inherent in this method of solution are indicated and estimates are made of their magnitudes. A comparison of the method with Slater's perturbation theory is made.

A Graphical Method for Transforming Impedances and Reflectances Through a Lossy Twoport—O. F. Hinckelmann (p. 139)

In this paper a simple projective geometric construction is applied to the problem of finding the input impedance of a linear lossy twoport junction for a given output port termination. The method, an extension of Bracewell's transducer diagram, is presented in both the impedance and reflectance planes.

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Nuclear Science

Vol. NS-9, No. 2, April, 1962

A High Current Radio Frequency Proton Source with Radial Extraction—M. E. Abdelaziz (p. 1)

A theory outlining the mechanism of the low pressure hydrogen plasma used in radio frequency proton sources is given. Taking into account secondary emission from surfaces of plasma vessel it is shown that the electron density is maximum at the tube's center. This is confirmed experimentally, and a source is designed with its extraction electrode positioned radially near the plasma center. Compared with axial extraction used in conventional r.f. sources, radial extraction yields beam currents over 20% higher, and allows the application of higher extraction voltages. Beam currents up to 150 Ma. can be extracted, of which more than 85% is proton current. Two methods are used for the measurement of the emittance of the accelerated beam.

The R.F. System for the Princeton-Pennsylvania Accelerator—J. L. Kirchgessner, D. Barge, G. K. O'Neill, G. Rees, and J. Riedel (p. 11)

Advances in High Power Distributed Amplifiers—D. A. Barge

The high power distributed amplifier system for the Princeton-Pennsylvania Accelerator employes a total of 166 Eimac 4CX300A tetrodes to achieve an average power gain of 5000. The system is designed to work over a range of frequencies of 2.5 to 30 Mc/s, but is capable of amplifying 60 Mc/s at a reduced duty cycle. The high level stages of the system limit the effective duty cycle to 25%, at the normal range of frequencies. Design criteria and practice are discussed.

Wideband Precision Phase Detector—C. L. Kang (p. 26)

A phase error detecting system designed for the RF system of the 3-Bev Princeton-Pennsylvania Proton Synchrotron is described. It serves as a link in the servo loop to keep ferrite tuned RF load to track the driving signal which sweeps from 2.5 to 30 mc/s at repetition rate of 20 cps. The input signals are shifted to a constant intermediate frequency of 455 kc/s by mixing with a specially generated tracking signal. Limiting, phase shifting, and the phase detection are all done at 455 kc/s. Its output phase lag for phase modulation frequency below 50 kc/s is less than 90°. It has a usable range of 40 db input variation. Zero output accuracy is ±2° for the range of 20 db input variation. All circuits, except the tracking signal generator are transistorized.

Some Aspects of Electron Beam Optics and X-Ray Production with the Linear Accelerator—J. Haimson (p. 32)

Part I—A mathematical presentation of linear accelerator fundamental design parameters leads to optimization formulae for X-ray output and operational stability. A narrow spread of electron energies is desirable in most linear accelerator applications and especially when post-acceleration beam bending is utilized to project a stable high energy X-ray beam at right angles to the accelerator waveguide.

Part II—Some consideration is given to electron source optics and an analysis of a chopped prebunched injection system is presented together with a comparison of different types of buncher design with emphasis on obtaining narrow energy spectrum small cross-section electron beams. A method of analysing prebunched injection current and buncher acceptance characteristics is described.

An External Beam Bunch Selector for a 60-Inch Cyclotron—T. E. Fessler and J. S. Vincent (p. 50)

An external beam-bunch selector has been built to modulate the beam of the NASA 60-inch cyclotron for neutron time-of-flight studies. Electrostatic deflection at one-fourth the cyclotron frequency is used to lengthen the beam burst period, so that longer flight times can be used. The design and performance of this apparatus are described. With this equipment, flight times up to 400 nanoseconds are available, without distortion of the cyclotron beam burst width. Energy resolutions of the order of 2 per cent are thus possible.

Design Features of a High-Current Pulsed Electron Accelerator—W. A. S. Lamb (p. 53)

The design features of an induction electron accelerator which is under construction at the Lawrence Radiation Laboratory at Livermore, California, are described. The basic parameters are beam energy 4 Mev, beam current 200 amperes, pulse length 0.25 μsec, repetition rate 60 per second. The design beam quality is to be $<10^{-2}$ radian-cm and the energy spread is to be ±0.5% during the useful part of the pulse. The accelerator consists of a gun whose output is 720 kev, followed by six modular units of 570-kev output each. Several unique components have been developed for use on this machine; among them are a 10-inch-diameter cathode and an accelerating column made of metal-ceramic seals 14 inches in diameter for use on the gun.

This accelerator is being constructed for use in experiments on the "Astron, concept for heating and containing hot plasma.

Development of 36-Megawatt Modulators for the Astron 1000-Megawatt Electron Accelerator—V. L. Smith (p. 57)

A 1000-megawatt peak-power linear electron accelerator is required for the injection of electrons into a thermonuclear fusion experimental device, called the Astron, which is now under construction at the Lawrence Radiation Laboratory in Livermore, California. The Astron will determine the feasibility of an actual power-producing fusion reactor utilizing the principles of confinement and heating of a plasma by establishing a long rotating layer of relativistic electrons. The linear electron accelerator under construction is designed to produce a pulsed electron beam with an energy of 5 Mev ±0.5%, a pulse current of 200 amperes, with a pulsed duration of 0.25 μsec and at 60 pulses per second. The accelerator will be of the induction type utilizing large magnetic cores. Approximately 400 cores will be used and each one will contribute a minimum acceleration of 12,000 volts. The details of the design and development of a line-type modulator used for pulsing cores and capable of an output peak power of 36 megawatts will be discussed in detail. A type 6587 and type 5949A thyratron were life-tested at 32 kv, 2000 amperes, and 60 pps. Useful life in excess of 1000 hours was obtained. In addition, it was necessary to develop corona-resistant connectors for this application. Life data and final design for a small connector suitable for operation at 16-kv, 0.4-μsec (70% amplitude points) pulses with 60-nanosecond rise time, and at 60 pps are presented.

A High-Voltage Electrolytic Capacitor Bank—D. B. Hopkins and P. F. Pellissier (p. 68)

For controlled thermonuclear devices of moderate volume employing externally applied magnetic fields, the magnetic energy requirements extend into the megajoule range. A high-voltage series-parallel bank of electrolytic capacitors can supply this energy reliably and inexpensively. The total cost of the bank, including charging supplies, controls, and labor, is less than 14 cents per joule. Required floor space, including access and service area, is about 250 ft²/Mj. A 5-kv electrolytic bank storing 150 kj has been in routine operation since 1958, and is currently being extended to 1 Mj. The bank is composed of 80 modular 12.5 kj sections, each module being a 12-by-12 series, parallel array of 1000-μf 450-v, standard electrolytic capacitors. Each module has its own charging, switching, and fault-sensing circuits. Including external voltage dividers and internal leakage current, about 24w/kj is required to maintain the bank at full voltage. Normal one-quarter cycle discharge times are in the millisecond range with repetition rates ranging from one-half to 15 or more per minute, depending on the external circuit. Capacitor life is measured in years, is dependent upon the time required for the electrolyte to dry out, and is virtually unaffected by the operating schedule of the bank. Flexibility in the usage of the bank is ensured by having multiple output-switching ignitrons in each module. Sequencing and control circuitry provides for time-sharing of the bank by up to five users, each having independent control of bank capacity and voltage.

The Energy Storage System for A 3.5-Megajoule Magnetic Compression Experiment—T. M. Putnam and E. L. Kemp (p. 74)

The Scylla experimental program has shown that a small volume of high temperature ($>10^7$°K) plasma can be produced by the application of a fast-rising, sinusoidal, axial magnetic field to a volume of partially ionized deuterium gas. The apparatus described was designed to produce a plasma with the same final density and temperature as in a net energy-producing plasma but for a much shorter containment time. However, the magnetic half period will be of sufficient length to allow the stability problem to be studied thoroughly. The engineering aspects of the 3.5 Mjoule experiment, Scylla IV, are discussed in detail. The basic problems in the design are those of minimizing the source inductance, providing electrical insulation for tens of kilovolts and providing transmission systems and switches capable of handling currents of 20 to 30 megamperes. The design of the capacitor banks, switching system, cabling and cable headers, and collector plates is described.

Space Powerplant Shield Design Optimization—F. L. Bouquet, Jr. (p. 83)

The use of either nuclear reactor or radioisotope powerplants in space requires nuclear radiation shielding for personnel and equipment. When certain approximations are valid, a simplified method permits rapid shield design. The equations for two-layer and three-layer shields are presented, and the limitations of the equations are indicated.

The Selection of Optimum Time Constants for RC Filters with Random Signals—R. A. Harvey (p. 85)

The application of statistics to the measurement of random signals, with particular emphasis on count-rate-meters, is considered. It is shown that under certain criteria, there are optimum values of time constants in the count-rate-meter circuit that will produce the desired results. While the emphasis is placed on the count-rate-meter, the same approach can be used to measure signals in the presence of noise where RC type smoothing is present.

Limits of Resolution in Magnetically Focused Image Converter Tubes—G. Papp (p. 91)

In a simple image tube in which the uniformly accelerated electrons are focused by a homogeneous magnetic field onto the phosphor, the error in focusing due to the arbitrary initial velocity of the photoelectrons is calculated. It is shown that optimum resolution can be obtained if focusing is adjusted for electrons leaving the cathode at the average initial forward velocity. A method to measure the initial average transverse velocity in the tube itself is developed. A practical formula for the expected resolution is derived (see Equation 12) for tubes with S-11 photocathodes and for the incident light coming from a slightly underheated incandescent lamp.

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Tracking Systems Employing the Delay-Lock Discriminator—M. R. O'Sullivan (p. 1)

The delay-lock discriminator is a statistically optimum device for measuring the delay between two correlated waveforms. Its theory of operation and the performance of an experimental model have been described by Spilker and Magill. The application of this device to range- and angle-measuring systems is discussed herein. Utilization of the delay-lock discriminator can lead to substantial simplification as compared to tracking systems relying exclusively on phase-lock loops. Such improvements result because the delay-lock loop is free of the ambiguities inherent in phase-lock measurements.

The characteristics of presently available delay lines, an essential component of the delay-lock loop, and, in particular, the limited accuracy of which they are capable at present prohibits the immediate exploitation of the full capability of the delay-lock technique. For this reason, an attractive possibility for an immediate implementation is a hybrid system in which a delay-lock measurement is made to resolve ambiguities, while a phase-lock measurement determines the ultimate accuracy.

A combined range- and angle-tracking system employing this hybrid concept is described herein, in which the delay-lock measurement is made on a low-pass noise waveform which, for transmission purposes, is applied as amplitude modulation to a stable carrier. The precise measurement is made by phase-locking onto the carrier. The phase-lock output is also used to synchronously detect the low-pass modulation.

The characteristics of this system are discussed and expressions are given which show the dependence of threshold SNR and rmns delay error upon system parameters. Its theoretical performance is illustrated in tracking a cooperative (*i.e.* transponder-bearing) vehicle at a range of 500 miles moving with a velocity of 30,000 ft/sec. For this mission, the theoretical accuracy in the absolute value of range is 50 ft while relative range information to an accuracy of 1 ft is provided. The theoretical angular accuracy is 2×10^{-5} radians and the transmitted power required is a modest 100 mw.

Piecewise Linear Analysis of Phase-Lock Loops—C. R. Cahn (p. 8)

The synchronizing performance of a phase-lock loop, in the absence of noise, is obtained by replacing the sinusoidal characteristic of the product demodulator, as a function of phase difference, by a triangular piecewise linear approximation. The analytical conditions for existence of a limit cycle (steady-stage asynchronous mode) with a steady input frequency are derived. They may be solved numerically for any limit cycle, and a constrained minimization yields the minimum mistuning of the input carrier for which a limit cycle exists. Inside of this computed synchronization limit, an asynchronous mode does not exist.

The computation for a particular case (damping factor = 0.5) yields a synchronization limit very similar to previous analog computer results. It is found that for a relatively large ratio of noise bandwidth to hold-in range, the synchronization limit corresponds to a trajectory connecting adjacent unstable points in the phase plane. However, for a small ratio, the solution changes character, and the synchronization limit is found to become proportional to the square root of loop-noise bandwidth. This is in agreement with a conclusion reached by Gruen on the basis of experimental data and by Viterbi by another approximate method of analysis.

Classification and Evaluation of Coherent Synchronous Sampled-Data Telemetry Systems—A. Viterbi (p. 13)

This paper analyzes the various types of continuous wave and pulse modulation for the transmission of sampled data over channels perturbed by white Gaussian noise. Optimal coherent synchronous detection schemes for all the different modulation methods are shown to belong to one of two general classes: linear synchronous detection and correlation detection. The figures of merit, mean-square signal-to-error ratio and bandwidth occupancy, are determined for each system and compared.

Clock Sources for Synchronized Communication Systems—R. C. Mackley (p. 23)

The ideal clock source will have start-stop capability, maintain known phase with respect to a start signal and combine high-frequency stability with voltage tuning to permit phase lock and Doppler correction. These properties define a clock source suitable for synchronized communication systems in which a remote unit must be started in synchronism with the signal received from a local unit. For some space applications clock stabilities of the order of one part in 10^7 may be required.

The two approaches to the problem considered are the gated crystal oscillator and the gated divider chain. The first requires that a high Q crystal oscillator be turned on in essentially steady state with insignificant transients of amplitude and phase. In the second a continuously running crystal oscillator is gated into a series of count-down dividers to obtain the clock output. Both of these approaches will will produce circuits that have the required properties.

Luneberg Lenses for Space Communications—R. C. Rudduck and C. H. Walter (p. 31)

The purpose of this paper is to create greater familiarity with recent developments in Luneberg lenses and to point out their usefulness in space communications. The term Luneberg lens is widely used to denote any lens having a radial variation in index of refraction. As a result of the radial variation in index a Luneberg lens antenna may scan a full 360° by feed movement alone or simultaneous coverage in many directions may be accomplished by using multiple feeds.

In the sections that follow the present state of the art with regard to Luneberg lens antennas and reflectors is briefly summarized and some examples to illustrate the use of Luneberg lenses in space communications systems are given. Lens structures are discussed as well as the possibility of using the atmosphere of a planet as a gigantic lens.

A Note on Demodulation of PCM/PM Signals with Seitching-Type Phase Detectors—J. A. Develet, Jr. (p. 39)

This paper presents formulations which relate average received signal power, noise density, and bit rate of the source to the expected probability of bit error in the received information for binary phase modulations systems.

The performance of these systems is analyzed for the practical case of demodulation with switching-type phase detectors and the performance is compared with optimal product demodulation.

The received signals are assumed corrupted with additive white Gaussian noise.

The following modulations are analyzed explicitly:

1) Direct-carrier phase reversal,
2) Squarewave-subcarrier phase reversal,
3) Sinusoidal-subcarrier phase reversal.

It is shown that direct-carrier and squarewave-subcarrier phase reversal modulations are optimally demodulated with the switching-type phase detector. The sinuosidal-subcarrier phase reversal modulation, however, is not optimally demodulated by this method. The degradation from optimal product demodulation is slight for modulation indices of 2 radians or less but becomes greater for larger indices.

DIGILOCK Telemetry System for the Air Force Special Weapons Center's Blue Scout, Jr.—R. M. Jaffee (p. 44)

The Blue Scout, Jr. is a sounding rocket which will be instrumented to measure various forms of radiation at altitudes up to 100,000 miles. Space-General Corporation has built a Digilock telemetry system to convey the radiation information from the vehicle to the earth. The telemetry flight-unit communicates twenty 5-bit digital inputs, encodes the selected words into one of a family of binary orthogonal codes (the particular code selected depending on the value of input data), and phase modulates a transmitter with the selected code sequences. At the ground station the signal is fed to a specially designed phase-lock receiver, which demodulates the phasing information on the received signal and applies the video information (which is binary in the absence of noise) to a tape recorder. The tape is played back at the data-reduction center; the played-back signal is filtered by an integrate-and-dump circuit and then re-recorded on tape in a format suitable for processing by an IBM computer, which, by mechanizing a matched-filter type of decoder, yields the originally transmitted radiation data.

Because of the orthogonal nature of the transmitted codes and the method used for modulation and demodulating the r-f carrier, it is possible to achieve a communication efficiency which is unsurpassed by any other existing system. In the present application, the Digilock system conveys information at a rate of approximately 64 bits/sec from a distance of 100,000 miles using only one-quarter watt of transmitted power; the resulting error rate per information bit is considerably less than 10^{-6}.

The Nature of Astro Doppler Velocity Measurement—J. E. Abate (p. 50)

This paper deals with astro Doppler velocity measurement for space vehicle navigation. The measurement yields the relative velocity of the vehicle with respect to a star, and requires the use of electro-optical systems capable of measuring a small incremental change in the wavelength of propagated stellar energy. Such systems provide velocity data whose character and limitations are a function of the star's spectral radiation as well as the system instrumentation. This paper discusses the astro velocity data, its derivation, character and limitations; and the Doppler velocity systems, their capabilities, limitations, and possible instrumentation.

Twelve Advantages of Stationary Satellite Systems for Point-to-Point Communication—S. G. Lutz (p. 57)

With the exception of those systems which are intended to satisfy special military requirements, passive satellite communication systems will not be economically competitive with high-capacity, active satellite systems because of greater terminal costs. There are twelve reasons why stationary orbit systems should become the backbone of future global communications, and these are discussed in detail. Seven of these are based on economic and system advantages, while the remaining five arise from interference coordination advantages in frequency sharing among satellite systems and with surface services. Stationary satellites present space technology and propagation delay problems, but these are rapidly being overcome. It is therefore recommended that more planning and regulatory emphasis be focused on stationary satellite communication systems, since nonstationary, nonmilitary systems will only be interim or supplementary systems.

Correspondence (p. 66)

Abstracts and References

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NOTE: The Institute of Radio Engineers does not have available copies of the publications mentioned in these pages, nor does it have reprints of the articles abstracted. Correspondence regarding these articles and requests for their procurement should be addressed to the individual publications, not to the IRE

Acoustics and Audio Frequencies 1731
Antennas and Transmission Lines 1732
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The number in heavy type at the upper left of each Abstract is its Universal Decimal Classification number. The number in heavy type at the top right is the serial number of the Abstract. DC numbers marked with a dagger (†) must be regarded as provisional.

UDC NUMBERS

Certain changes and extensions in UDC numbers, as published in PE Notes up to and including PE 666, will be introduced in this and subsequent issues. The main changes are:

Artificial satellites:	551.507.362.2	(PE 657)
Semiconductor devices:	621.382	(PE 657)
Velocity-control tubes, klystrons, etc.:	621.385.6	(PE 634)
Quality of received signal, propagation conditions, etc.:	621.391.8	(PE 651)
Color television:	621.397.132	(PE 650)

The "Extension and Corrections to the UDC," Ser. 3, No. 6, August, 1959, contains details of PE Notes 598–658. This and other UDC publications, including individual PE Notes, are obtainable from The International Federation for Documentation, Willem Witsenplein 6, The Hague, Netherlands or from The British Standards Institution, 2 Park Street, London, W. 1, England.

ACOUSTICS AND AUDIO FREQUENCIES

534.2-14 **1789**

Propagation of Plane Sound Waves of Finite-Amplitude in Nondissipative Fluids—D. T. Blackstock. (*J. Acoust. Soc. Am.*, vol. 34, pp. 9–30; January, 1962.) An extensive theoretical treatment is presented of the problem of plane progressive sound waves (simple waves) produced by continuous high-amplitude motion of a piston in a lossless, semi-infinite tube. A brief analysis of shock formation is also given.

A list of organizations which have available English translations of Russian journals in the electronics and allied fields appears each June and December at the end of the Abstracts and References section.

The Index to the Abstracts and References published in the PROC. IRE from February, 1961 through January, 1962 is published by the PROC. IRE, June, 1962, Part II. It is also published by *Electronic Technology* and appears in the March, 1962, issue of that Journal. Included with the Index is a selected list of journals scanned for abstracting with publishers' addresses.

534.232-8 **1790**

Solid Mixtures with Specified Impedances and High Attenuation for Ultrasonic Waves—A. Lutsch. (*J. Acoust. Soc. Am.*, vol. 34, pp. 131–132; January, 1962.) The backing material used for increasing the bandwidth of an ultrasonic transducer must have characteristics which reduce back reflections. Production techniques are described.

534.24-14:534.88 **1791**

Long-Range Shallow-Water Bottom Reverberation—K. V. Mackenzie. (*J. Acoust. Soc. Am.*, vol. 34, pp. 62–66; January, 1962.) A theory is presented from which the 200–3000-cps bottom reverberation from very great ranges in shallow water is calculated. Typical computed curves are presented for reverberation level and reverberation strength as a function of the range/water-depth ratio.

534.24-14:534.88 **1792**

Long-Range Shallow-Water Signal-Level Fluctuations and Frequency Spreading—K. V. Mackenzie. (*J. Acoust. Soc. Am.*, vol. 34, pp. 67–75; January, 1962.) The fluctuation of the received sound for frequencies of 350, 700, 1200 and 2400 cps was studied for transmission over flat 60-fathom sand and 50-fathom sandstone bottoms out to ranges of 15 miles. The received sound fluctuated over a range of 50 db. Expressions are derived for the frequency spread due to the transmission process.

534.6 **1793**

Measurement of Acoustic Parameters and Properties of Materials—G. W. Becker, H. G. Diestel, and W. Mühe. (*Arch. tech. Messen*, no. 311, pp. 283–286; December, 1961.) Survey of measurement techniques covering the whole field of acoustics. 143 references.

534.61-8:621.3.018.75 **1794**

Measurement of the Distortion of Finite Ultrasonics Waves in Liquids by a Pulse Method—R. P. Ryan, A. G. Lutsch, and R. T. Beyer. (*J. Acoust. Soc. Am.*, vol. 34, pp. 31–35; January, 1962.) An RF pulse system is described for investigating progressive distortion of finite-amplitude waves propagating in liquids. The system employs pulses short enough to avoid reflections but long enough to approach continuous wave conditions.

534.75 **1795**

The Formation of Audibility Thresholds and Masking Thresholds for Continuous Sound—H. Scholl. (*Frequenz*, vol. 15, pp. 58–64; October, 1961. Special Issue.) Zwicker's model of sound perception (1003 of 1958) is extended, and discrepancies in the results of measurements are discussed.

354.76:621.396.97 **1796**

The Problem of Compatible Stereo-ambiophonic Sound Transmission on Two Channels—L. Keibs. (*Tech. Mitt. BRF, Berlin*, vol. 5, pp. 104–112; September, 1961.) Definition of "auditory perspective" (390 of 1961) and discussion of its realization by stereoreverberation methods [*e.g.*, 1065 of 1959 (Vermeulen)].

534.79(083.72) **1797**

Loudness: Terminology—(*Nachrtech. Z.*, vol. 14, pp. 623–625; December, 1961.) Definitions are proposed of terms relating to loudness and thresholds of hearing.

534.861 **1798**

Architectural and Room Acoustics of the New Sound Studio of the Südwestfunk at Freiburg/Br—R. Thiele. (*Rundfunktech. Mitt.*, vol. 5, pp. 311–313; December, 1961.) Results of acoustic tests are given.

534.861:621.396.712.3 **1799**

The Design of Small Studios and Listening Rooms—P. Schubert and F. Steffen. (*Tech. Mitt. BRF, Berlin*, vol. 5, pp. 113–117; September, 1961. Correction, vol. 5, 189; December, 1961.) The influence of room shape on the distribution of low-frequency natural modes is investigated and design improvements are suggested on the basis of the results obtained.

534.861:621.396.712.3 **1800**

The Operation of the New Sound Studio of the Südwestfunk at Freiburg/Br—L. Heck and A. Weingärtner. (*Rundfunktech. Mitt.*, vol. 5, pp. 314–321; December, 1961.) System design and the operational plan of the studio are detailed. See also 1798 above.

534.88 **1801**

The Back-Scattering of Acoustic Waves in Water by an Obstacle—R. W. G. Haslett. (*Proc. Phys. Soc.* (*London*), A, vol. 79, pp. 542–571; March, 1962.)

Part 1—Design of a Scale Model and Investigation of its Validity (pp. 542–558). The performance of standard targets and supports for small obstacles and other tank parameters were evaluated.

Part 2—Determination of the Reflectivities of Solids using Small Specimens (pp. 559–571). The reflectivities of fish tissues and materials suitable for models were measured.

621.395.61+621.395.623.7 **1802**

Contributions to the Theory of Electroacoustic Transducers—F. Spandöck. (*Fre-

quenz, vol. 15, pp. 29–33, and nos. 11 and 12, pp. 365–371 and 404–412; October–December, 1961. Special Issue.) The applicability of the formulas derived in 656 of 1956 is extended to transducers of higher order, and to irreversible transducers. A comparison is made with results obtained on the basis of the equivalent quadripole. Factors characterizing various types of transducers are calculated. 62 references.

621.395.616 1803
The Transducer Characteristics of High-Frequency Condenser Microphones—L. Schreiber. (*Frequenz*, vol. 15, pp. 353–357; November, 1961.) The RF capacitor microphone is treated as a passive reciprocal electromechanical quadripole.

621.395.623.7:621.317.3 1804
Measurements on Loudspeakers—M. Pöhls. (*Arch. tech. Messen*, no. 310, pp. 243–244; November, 1961.) Objective electrical and acoustic measurements of loudspeaker characteristics are discussed.

621.395.623.8 1805
Performance of Series-Parallel Speaker Arrays—J. F. Novak. (*Audio Engrg.*, vol. 45, pp. 23–37, 93; September, 1961.) A comparison is made of the characteristics of a single 6-in speaker, an array of 32 similar 6-in speakers, and a three-way system using crossover filters.

ANTENNAS AND TRANSMISSION LINES

621.372.2 1806
Propagation of Microwaves on a Single Wire: Part 3—V. Subrahmanyam. (*J. Indian Inst. Sci.*, vol. 44, pp. 27–48; January, 1962.) In a continuation of work reported earlier [Part 2: 3032 of 1957 (Contractor and Chatterjee)] theoretical results are presented for bare and dielectric-coated copper surface-wave lines. Variations of electrical parameters with the radius of the wire are examined and expressions derived which indicate directly the degree and nature of the radial field shrinkage as affected by the thickness of the dielectric coating.

621.372.2:[621.372.54+621.374.5 1807
A Study of the Phase and Filter Properties of Arrays of Parallel Conductors between Ground Planes—J. T. Bolljahn and G. L. Matthaei. (PROC. IRE, vol. 50, pp. 299–311; March, 1962.) A mathematical analysis of structures which include interdigital, hairpin and meander lines, a helix, and a reactively loaded comb line. Some of these have special merits as filters or as slow-wave structures. Practical examples are described.

621.372.823:621.372.853.1 1808
Determination of the Mode Conversion in Circular Waveguide with Irregular Dielectric Coating—W. Janssen. (*Arch. elekt. Übertragung*, vol. 15, pp. 525–536; November, 1961.) Disturbances resulting from H_{01}-mode conversion due to coating irregularities are analyzed. Partial compensation of the conversion products may occur.

621.372.83:537.226 1809
On the Junction of Rectangular Waveguides containing Dielectric—P. J. B. Clarricoats and P. V. Rogers. (*J. Electronics and Controls*, vol. 11, pp. 153–159; August, 1961.) Theoretical and experimental results show that over a frequency band 9–11 Gc the voltage SWR of the dielectric-loaded junction exceeds 0.93 compared with 0.6 unloaded.

621.372.831 1810
The Measurement of Tensor Permeability of Ferrites in Waveguide Couplers—W. Nowak. (*Hochfrequenz. und Elektroak.*, vol. 70, pp. 219–229; December, 1961.) The use of a crossed-waveguide coupler containing the ferrite specimen simplifies the measurement of tensor permeability. The results of experimental measurements are given.

621.372.832.43 1811
A Directional Coupler for U.H.F.—H. J. Fraisse. (*Frequenz*, vol. 15, pp. 341–344; November, 1961.) The operation of a ring-line type of coupling circuit is described. (A coupler of this kind has been constructed from microstrip elements.)

621.372.852.1:621.318.134 1812
Frequency-Selective Limiting in YIG Filters—K. L. Kotzebue. (*J. Appl. Phys.*, vol. 33, p. 747; February, 1962.) The results of experiments on a band-pass filter of Y-Fe garnet are presented showing its possible use as a frequency-selective limiter.

621.396.67.012.12 1813
Some Problems regarding the Measurement of Radiation Patterns of Aerials—D. Nowatzky. (*Tech. Mitt. BRF, Berlin*, vol. 5, pp. 129–133; September, 1961.) Methods of accurate measurement and of eliminating ground reflections are discussed.

621.396.677:523.164 1814
Interferometers for Radio Astronomy—Glass. (See 1903.)

621.396.677:523.164.4 1815
Design of Radio Telescopes for Extragalatic Surveys—Harrower. (See 1909.)

621.396.677.3:523.164 1816
Systems for Simultaneous Image Formation with Radio Telescopes—McLean and Wild. (See 1904.)

621.396.677.43 1817
Impedance Measurements on Rhombic Aerials and associated Transmission Lines—R. C. Barton and K. F. Ferres. (*Proc. IRE (Australia)*, vol. 23, pp. 13–21; January, 1962.) "The impedance/frequency characteristics of two 2-tier HF rhombic aerials and a 4-wire transmission line for a radio receiving station are investigated. The basic design and constructional features are briefly discussed."

621.396.677.832 1818
A Corner-Reflector Antenna Derived from the Square Loop—S. Prasad. (*Proc. Nat'l. Inst. Sci. India*, Pt. A, vol. 27, pp. 520–530; September, 1961.) Circuit and field properties of the aerial are studied and the input impedances and current distributions obtained by experiment for various sizes are compared with theoretical results. Radiation patterns are illustrated.

621.396.677.833 1819
Gain Limit and Tolerances of Large Reflector Aerials—A. Consortini, L. Ronchi, A. M. Scheggi, and G. Toraldo di Francia. (*Alta Frequenza*, vol. 30, pp. 776–787; November, 1961.) The effect on antenna gain of the dimensional tolerances of large reflectors is investigated, particularly for parabolic dishes. The optimum wavelength for a reflector of given dimensions and tolerances is also evaluated.

621.396.677.85:538.566 1820
The Propagation of Centimetric Electromagnetic Waves in an Absorbing Medium of Parallel Wires—Neumann. (See 1887.)

AUTOMATIC COMPUTERS

681.142:533.376 1821
An Electroluminescent Fixed Store for a Digital Computer—G. R. Hoffmann and P. L. Jones. (PROC. IRE, Pt. B, vol. 109, pp. 177–183; March, 1962.) A method of reading information from such a store is discussed and the operation of a matrix containing 128 digit positions is described.

681.142:621.318.042.1 1822
Circuit Protection for a Transistorized Magnetic Core Memory—W. A. Christopherson. (*Electronic Eng.*, vol. 34, pp. 234–237; April, 1962.) The system protects the storage elements against fault currents as low as 40 ma even though the normal operating current is 4–5 a.

CIRCUITS AND CIRCUIT ELEMENTS

621.3.049.7:621.382 1823
Minimum Size and Maximum Packing Density of Nonredundant Semiconductor Devices—J. T. Wallmark and S. M. Marcus. (PROC. IRE, vol. 50, pp. 286–298; March, 1962.) The essential active region in semiconductor devices is already close to minimum size. Further miniaturization of these devices must come from reduction in the size of nonessential parts.

621.3.049.75 1824
Modular Circuit Construction—P. H. Winter. (*Electronic Eng.*, vol. 34, pp. 173–175; March, 1962.) Circuits are constructed on a wiring board consisting of a laminated base board pierced with a regular matrix of holes. See also 1464 of May (Gosling).

621.318.134.042.1:538.24 1825
Some Considerations on Square-Loop Magnetic Core Circuits—K. Nagamori and T. Ishidate. (*NEC Res. Dev.*, no. 1, pp. 3–6; October, 1960.) Domain wall motion theory is introduced to correct the simple analysis for determining the driving impedance of a ferrite core. The results for peak output voltage are not changed by using the domain theory.

621.318.4:537.312.62 1826
Force-Free Coils and Superconductors—H. P. Furth and M. A. Levine. (*J. Appl. Phys.*, vol. 33, pp. 747–748; February, 1962.) A discussion of the prospects of building superconducting high-field coils, based on a force-free construction technique, which are suitable for operation in the range 100–200 kG.

621.318.43:537.312.62 1827
Superconducting Solenoids—R. W. Boom and R. S. Livingston. (PROC. IRE, vol. 50, pp. 274–285; March, 1962.) Graphs are presented which permit the application of a method, based on the Fabry formulation, for the approximate optimization of superconducting solenoids.

621.318.57:551.510.535:621.3.087.4 1828
A Sequence Switching Unit for Measurement of Ionospheric Drift—Bose. (See 1948.)

621.318.57:621.383.4 1829
Switching Elements consisting of Photoconductors and Triggered Neon Lamps—W. G. Gelling. (*Philips Res. Repts.*, vol. 16, pp. 501–506; December, 1961.) The properties of combinations of CdSe photoconductors with normal and triggered neon lamps are discussed. Some requirements of the lamp characteristics are given.

621.37/.38:061.3 1830
Circuit Designers Improve Practical Applications of Solid-State Devices—S. Weber, M. F. Wolff, and L. D. Shergalis. (*Electronics*, vol. 35, pp. 20–21; March, 1962.) A review of some of the low-noise amplifiers and microwave power sources using solid-state masers, tunnel diodes and varactors, featured at the Solid-State Circuits Conference, Philadelphia, Pa., 1962.

621.372.413:621.385.644.3 1831

Theoretical Analysis of an Interdigital Resonator with Radial Vanes—A. Singh. (Proc. IRE, Pt. B, vol. 109, pp. 145–149; March, 1962.) General expressions are derived for calculating, to successively better approximations, the resonant frequencies of modes perturbed by the vanes and anode. Examples of calculations are verified experimentally.

621.372.5 1832

Lumped Impedance Network Transformation—W. Wharton. (*Electronic Tech.*, vol. 39, pp. 133–138; April, 1962.) Given the Y matrix of a network having n pairs of terminals, an equivalent network involving $\lambda/4$ transmission lines with n junction points is discussed.

621.372.5 1833

On the Network with the Minimum Number of Coils—H. Watanabe. (*NEC Res. Dev.*, no. 1, pp. 26–35; October, 1960.) Necessary and sufficient conditions for maximizing the degrees of freedom of an RLC network which contains a given number of inductances and resistances and an arbitrary number of capacitances are established. A method of determining the transfer function of a Chebyshev-type band-pass filter with a minimum number of coils is described.

621.372.5 1834

The Reduction of Unsymmetric Quadripoles between Different Terminal Resistances to Symmetric Quadripoles—W. Herzog. (*Arch. Elektrotech.*, vol. 46, pp. 312–320; October, 1961.)

621.372.5 1835

The Calculation of Build-Up Processes in Networks with Stagger-Tuned Individual Circuits and Large Relative Bandwidths—M. Locke. (*Hochfrequenz. und Elektroak.*, vol. 70, pp. 214–219; December, 1961.) The response to switching-on transients of two- and three-stage networks is calculated.

621.372.512.3 1836

Terminal Impedance and Gain of the Series-to-Parallel Transitionally-Coupled Circuit—G. J. A. Cassidy. (*J. Brit. IRE*, vol. 23 pp. 225–229; March, 1962.)

621.372.54+621.374.5]:621.372.2 1837

A Study of the Phase and Filter Properties of Arrays of Parallel Conductors between Ground Planes—Bolljahn and Matthaei. (See 1807.)

621.372.54:621.372.412 1838

Crystal-Filter Design—A. S. Chester. (*Electronic Tech.*, vol. 39, pp. 126–133; April, 1962.) A universal design graph gives filter characteristics of any quartz unit and termination. The technique described is specially suitable for multichannel applications.

621.372.54.049.7 1839

Theory and Examples of Application of a Circuit Element with Distributed Resistance and Distributed Capacitance—W. Minner. (*Arch. elekt. Übertragung*, vol. 15, pp. 537–544; November, 1961.) The component considered consists of a ceramic plate of high dielectric constants with a resistive coating on one side and a highly conductive coating on the other side. This circuit element is equivalent to an infinite number of cascade-connected RC filter sections. Applications discussed include a low-pass and a rejection filter, and a frequency-control element for an oscillator.

621.372.543.2 1840

Low-Q Band-Pass Filters—R. O. Rowlands. (*Electronic Tech.*, vol. 39, pp. 151–155; April, 1962.) A lossless filter design is modified to preserve the relative discrimination between a wanted frequency and an unwanted band when the filter elements are lossy.

621.372.543.2 1841

Variable Pass-Band RC Filter—A. A. Mahmoud. (*Electronic Tech.*, vol. 39, pp. 155–160; April, 1962.)

621.372.543.2:621.372.412 1842

Jaumann Structures with Capacitive Tapping for Band-Pass Crystal Filters—A. Fettweis. (*Rev. HF. Brussels*, vol. 5, no. 5, pp. 116–123; 1962. In English.) Symmetric and dissymmetric capacitive tapping of a band-pass filter transformer is considered, and a method of obtaining a maximum capacitance ratio in the branch to be replaced by a crystal is developed.

621.372.543.22 1843

The Influence of the Differential Transformer on the Attenuation Characteristic of Differential-Bridge Filters—W. Herzog. (*Frequenz*, vol. 15, pp. 344–353; November, 1961.)

621.372.6 1844

Duality of Nonplanar Electric Circuits without the Use of Ideal Transformers—M. Erdei. (*Proc. Phys. Soc.* (*London*), A, vol. 79, pp. 599–604; March, 1962.) A method of constructing the dual of any linear-lumped nonplanar network, which does not include magnetic coupling, is given without using ideal transformers.

621.372.622:538.632 1845

A Hall-Effect Microwave Mixer—H. E. M. Barlow and K. V. G. Krishna. Proc. IRE, pt. B, vol. 109, pp. 131–136; March, 1962.) A signal-frequency current and a magnetic field at the local-oscillator frequency produce a Hall-effect EMF at the IF across a semiconducting plate. The minimum conversion loss achieved is 57 db.

621.373.42.029.4 1846

A Survey of Very-Low-Frequency Oscillators—R. Brown. (*Brit. Commun. Electronics*, vol. 9, pp. 278–281; April, 1962.) Methods of generating frequencies below 16 kc for vibration work and for testing servomechanisms are outlined. The major characteristics of 34 instruments are tabulated.

621.373.52 1847

A High-Stability Transistor Oscillator for 400 Mc/s—N. P. Harvey, A. Poulett, and J. T. Zakrzewski. (*Electronic Eng.*, vol. 34, pp. 238–243; April, 1962.) The design, development, construction and testing of a 400-Mc oscillator are described. Power output is stable within ±12 per cent and frequency within ±450 kc over the temperature range −30 to +70° C.

621.374.3:621.382.333 1848

Spikes on Chopper Transistor Waveforms—J. Palmer. (*Electronic Eng.*, vol. 34, pp. 163–167; March, 1962.) The effect of load resistance and capacitance on spike feed-through is investigated and the amplitude and rise and fall times are derived. A spike test for chopper transistors is recommended.

621.374.3:621.382.333 1849

Avalanche Pulse Generators—H. G. Dill. (*Semiconductor Prod.*, vol. 5, pp. 23–30; February, 1962.) A method is given for optimizing the switching time and the pulse repetition rate of avalanche transistor operation.

621.374.32 1850

A Fast Counter for Adding and Subtracting Randomly Related Pulse Trains—W. H. P. Leslie and D. Nairn. (*Electronic Eng.*, vol. 34, pp. 227–233; April, 1962.) The circuits shown have a high speed of count propagation through a binary or binary decimal counter and are able to deal with random pulses on each line irrespective of the degree of overlap or separation of the pulses.

621.374.32:621.382.3 1851

Pulse Counting and Fast Scaling Transistor Circuits—F. H. Wells and J. G. Page. (*J. Brit. IRE*, vol. 23, pp. 231–235; March, 1962.) A review of scaling circuits and some typical designs.

621.374.4:621.318.134 1852

Millimetre-Wave Harmonic Generation in Ferrites—C. S. Gaskell. (Proc. IRE, vol. 50, p. 326; March, 1962.) A ferroxcube D5 doubler driven at a fundamental of 35 Gc was found to have a minimum conversion loss of 13 db when the output waveguide was polarized parallel to the input.

621.374.4:621.387 1853

Microwave Harmonic Generator capable of Frequencies in Excess of 600 Gc—K. D. Froome. (*Nature*, vol. 193, pp. 1169–1170; March, 1962.) The device contains argon at 400 atmospheres which reduces the 450-ma arc produced between cathode and anode to a small cathode spot. The microwave signal "driving" the arc is a continuous wave of about 5 w. An output of 0.002 μw at 630 Gc, the 18th harmonic of the drive input, is obtained.

621.375.1 1854

Gain and In-Phase Suppression of Symmetric and Unsymmetric Differential Amplifiers—H. Werner. (*Nachrtech.*, vol. 11, pp. 508–515; November, 1961.) The equivalent circuit of the differential amplifier is given and the operating parameters are calculated.

621.375.4 1855

Transistor Differential Amplifier—K. P. P. Nambiar. (*Electronic Tech.*, vol. 39, pp. 147–151; April, 1962.) The design concepts of and experimental results obtained from a drift-compensated cross-coupled amplifier are discussed.

621.375.432.9.024 1856

Thermal Feedback in a D.C. Transistor Amplifier—G. Faini and O. Svelto. (*Alta Frequenza*, vol. 30, pp. 830–833; December, 1961. In English.) Thermal feedback is applied via resistance windings around two transistors of a balanced input stage. It is only effective at very low frequency, and its reduces dc drift. Experimental results are given.

621.375.9:538.569.4 1857

Optical Pumping of Masers using Laser Output—J. F. Ready and D. Chen. (Proc. IRE, vol. 50, pp. 329–330; March, 1962.) Using ruby with a total Cr ion concentration of about 10^{19}/cm^3 an inversion of approximately 8×10^{17}/cm^3 (between levels 3 and 2, and for several hundreds of microseconds) is predicted, which should give stimulated emission at 6.4 Gc. Apparatus is being made to demonstrate this.

621.375.9:621.372.44 1858

Reduction of the Noise Figure of an Amplifier by a Negative Conductance in its Input Circuit—A. Baelde, H. Groendijk, and M. T. Vlaardingerbroek. (*J. Electronics and Control*, vol. 11, pp. 177–187; September, 1961.) The lowest noise figure is obtained when the negative conductance is infinitely great. In practice a minimum noise figure exists only if the lowest permissible value of stability or bandwidth is given.

621.375.9:621.372.44 1859

Quasi-Cascaded Parametric Amplifier—W. B. Ribbens. (*J. Appl. Phys.*, vol. 33, pp. 757–758; February, 1962.) A description is given of a circuit based on the resonance modes of a single sample which should significantly improve the power gain of current Suhl-type amplifiers.

621.375.9:621.372.44:621.372.632 1860

Parametric Energy Conversion by Nonlinear Admittances—R. S. Engelbrecht. (Proc. IRE, vol. 50, pp. 312–321; March, 1962.) Circuits employing nonlinear resistances and capacitances are described which can yield unconditionally stable up-conversion gains considerably in excess of the output/input frequency ratios. The down-conversion loss can be made simultaneously high.

621.375.9:621.372.44:621.382.23 1861

Broad-Band Parametric Amplifiers by Simple Experimental Techniques—B. B. Bossard and R. Pettai. (Proc. *IRE*, vol. 50, pp. 328–329; March, 1962.) Maximum use is made of the parasitic elements of the varactor diode, and simple measurements enable the diode unit with the best $|V_c/V_0|$ characteristics to be chosen. The pass-band characteristics of diode-mount combinations are also measured. Single-channel gain-bandwidth products approaching 3.3 Gc have been achieved.

621.375.9:621.372.44:621.382.23 1862

900-Mc/s Nondegenerate *X*-Band Amplifiers—K. M. Johnson. (Proc. IRE, vol. 50, p. 332; March, 1962.) The parametric amplifier described uses a GaAs pill varactor diode, it has a gain of 10 db and a noise figure of 3.2 db. With more pump power, greater gains should be realizable at bandwidths equal to or slightly less than 900 Mc.

621.375.9:621.372.44:621.385.6 1863

The Efficiency of Electrostatic Quadrupole Amplifiers—Curnow. (See 2124.)

621.375.9:621.372.44:621.396.621 1864

Parametric Amplifier Improves Troposcatter System—W. L. Smoot and H. C. Leahy. (*Electronics*, vol. 35, pp. 38–40; March, 1962.) Design details are given of an amplifier operating at 4400–5000 Mc which improves the performance of an existing communications reciever.

621.375.9:621.382.23 1865

Tunnel-Diode Straight Amplifier as Low-Noise Preamplifier Stage for the U.H.F. Range—H. Rieck and R. Maurer. (*Arch. elekt. Übertragung*, vol. 15, pp. 495–507; November, 1961). The signal and noise characteristics are investigated of a conventional triode amplifier with a tunnel-diode circuit as preamplifier stage, and experimental results obtained at 500 and 600 Mc are found to agree well with theory. For similar investigations on a diode-reactance preamplifier see 93 of 1961 (Maurer, *et al.*).

621.376.22 1866

The Problem of Nonlinear Signal Distortion in Ring Modulators—H. Meyer. (*Frequenz*, vol. 15, pp. 357–364 and 413–419; November and December, 1961; and vol. 16, pp. 61–65; February, 1962.) Theoretical and experimental investigation, particularly of third-order distortion.

621.376.32:621.398 1867

Self-Reactance Modulation in Telemetry Oscillators—T. M. Conrad. (*Electronics*, vol. 35, pp. 35–37; March, 1962.) Design formulas are given for predicting the frequency characteristics of VHF and UHF transistor oscillators.

GENERAL PHYSICS

537.228.4 1868

Microwave Modulation of Light using the Kerr Effect—D. F. Holshouser, H. Von Foerster, and G. L. Clark. (*J. Opt. Soc. Amer.*, vol. 51, pp. 1360–1365; December, 1961.) Modulation of light at 3 and 6 Gc is achieved by applying a superimposed es and microwave field to a CS_2 Kerr cell which is incorporated within the high-electric-field region of a resonant cavity. See also 3430 of 1961 (Kaminow).

537.29 1869

Drift Mobility of an Ionic Impurity in an Electric Field—J. R. Manning. (*Phys. Rev.*, vol. 125, pp. 103–108; January, 1962.)

537.311.33 1870

On the Theory of Surface States—E. Antončík. (*J. Phys. Chem. Solids*, vol. 21, pp. 137–145; December, 1961.) A new method is proposed for calculating Shockley-type surface states.

537.32:537.29 1871

Thermoelectric Phenomena associated with Electron-Field Emission—P. H. Levine. (*J. Appl. Phys.*, vol. 33, pp. 582–587; February, 1962.) The equilibrium temperature distribution in an ideal metal rod, one end of which is subjected to an intense electric field, is studied. The application of the system use as a heat pump is considered.

537.525 1872

An Analytical Solution for the Effect of Space Charge in Cold-Cathode Gas Discharges—J. Lucas. (*J. Electronics and Control*, vol. 11, pp. 281–287; October, 1961.) By using a simple mathematical model, an analytical solution for the Varney space-charge equation is obtained. This is in good agreement with the exact solutions computed by Ward (1833 of 1959).

537.525 1873

Current Buildup in Neon Gas Discharges at Small Overvoltages—B. T. McClure. (*Phys. Rev.*, vol. 125, pp. 11–16; January, 1962.) The increase is exponential; the time constant is calculated theoretically assuming that the discharge is sustained by secondary emission from the cathode caused by Ne^+ ions and metastable Ne atoms. There is good agreement with experiment.

537.533 1874

Perturbation of Electron Flow—G. Kent. (*J. Appl. Phys.*, vol. 33, pp. 683–686; February, 1962.) A perturbation analysis of single-stream quasi-static nonrelativistic electron flow is developed, based on the nonlinear equation for the velocity field.

537.56 1875

The Frequency of Nonlinear Plasma Oscillations—H. Derfler. (*J. Electronics and Control*, vol. 11, pp. 189–192; September, 1961.) The frequency of plane standing waves of electrons moving through a background of infinitely heavy ions is independent of amplitude if the electron velocity is a unique function of position. This is not true for spherical and cylindrical plasma oscillations.

537.56:[534.2+538.566 1876

Wave Propagation in a Partially Ionized Medium—A. Baglin. (*J. phys. radium*, vol. 22, pp. 811–820; December, 1961.) Theoretical treatment of the propagation and damping of low-frequency waves in an infinite uniform partially ionized medium in a longitudinal magnetic field. Two longitudinal modes, one an acoustic wave, and two transverse uncoupled modes are identified.

537.56:538.69 1877

Demonstration of Classical Plasma Behaviour in Transverse Magnetic Field—D. A. Baker and J. E. Hammel. (*Phys. Rev. Lett.*, vol. 8, pp. 157–158; February, 1962.) A demonstration that the removal of the internal electric field halts the streaming of the plasma transverse to the B field.

537.56.08 1878

Notes on the Effect of Noise on Langmuir Probe Characteristics—A. Garscadden and K. G. Emeleus. (*Proc. Phys. Soc.* (*London*), *A*, vol. 79, pp. 535–541; March, 1962.) The effects of periodic fluctuations of electron temperature, random current and space potential are considered. In many cases the electron concentration will be underestimated.

537.56.08 1879

***X*-Band Measurement of Shock-Tube Plasma Temperature**—S. J. Peperone. (*J. Appl. Phys.*, vol. 33, p. 767; February, 1962.) The radiation temperature of a plasma behind a hypersonic shock wave is measured using a microwave receiver. Results indicate that the temperature is approximately 4000°K.

537.56.08:621.372.413 1880

Resonances of a Microwave Cavity Partially Filled with a Plasma—B. Agdur and B. Enander. (*J. Appl. Phys.*, vol. 33, pp. 575–581; February, 1962.) The resonance characteristics of a cavity containing a cold plasma of arbitrarily large density are studied theoretically and experimentally. In addition to the modes of an empty cavity, a new class of modes is found.

537.568:621.385.6 1881

Possible Sources of Energy of Ion Oscillations in High and Ultra-High Vacuum—N. Eberhardt. (*Z. angew. Phys.*, vol. 12, pp. 560–565; December, 1961.) Two mechanisms are proposed to account for plasma oscillations arising in electron-beam amplifier devices. See, *e.g.*, 3702 of 1957 (Jepsen).

538.114 1882

Theory of Ferromagnetism and the Ordering of Electronic Energy Levels—E. Lieb and D. Mattis. (*Phys. Rev.*, vol. 125, pp. 164–172; January, 1962.) The ordering of the energy levels of a system of interacting fermions is considered mathematically.

538.221 1883

Stability of One-Dimensional Ferromagnetic Microstructures—W. F. Brown, Jr., and S. Shtrikman. (*Phys. Rev.*, vol. 125, pp. 825–828; February, 1962.) All nonuniform one-dimensional structures are found to be unstable: reasons for the stability of three-dimensional structures are given.

538.24 1884

Magnetic Decay in a Hollow Circular Cylinder—M. A. Weinstein. (*J. Appl. Phys.*, vol. 33, p. 762; February, 1962.) The rate of decay is found to depend on a dimensionless constant g, which is a function of the inner radius a and outer radius b of the cylinder. Numerical values of g have been computed for various ratios of a/b.

538.566:537.56 1885

Propagation of a Plane Electromagnetic Wave in a Plasma at Cut-Off and Beyond—R. Papoular. (*J. phys. radium*, vol. 22, pp. 749–758; November, 1961.) A complete solution of Maxwell's equations for two typical density distributions is used to demonstrate the limitations of the geometrical-optics hypotheses for thin plasmas.

538.566:537.56 1886

The Influence of Positive Ions on the Propagation of Electromagnetic Waves in Magnetized Plasmas—G. Seeger. (*Z. angew. Phys.*, vol. 13, pp. 551–560; December, 1961.) Theoretical investigations covering a wide range of frequencies up to gyro-frequency for the case of a homogeneous infinite plasma and a plasma confined by conducting walls, with propagation at various directions relative to the applied magnetic field.

538.566:621.396.677.85 1887

The Propagation of Centimetric Electromagnetic Waves in an Absorbing Medium of Parallel Wires—E. G. Neumann. (*Z. angew. Phys.*, vol. 13, pp. 509–517; November, 1961.) Experimental and theoretical investigation of the attenuation and wavelength of a plane wave in an artificial dielectric consisting of infinitely long, parallel, thin, poorly conducting wires forming a regular rectangular lattice.

538.566.029.64:537.56 1888

Measurement of a High Refractive Index for Transmission of 3-cm Microwaves through a Plasma—A. N. Dellis and J. M. Weaver. (*Nature*, vol. 193, pp. 1274–1275; March, 1962.) Propagation of 9-Gc signals between two antennas 11 cm apart in the afterglow of an argon discharge was studied. A strong magnetic field was applied. Propagation of the "whistler" mode was noted, and satisfactory agreement with the Appleton-Hartree equation was obtained.

538.569.4 1889

Spectral Diffusion Decay in Spin Resonance Experiments—J. R. Klauder and P. W. Anderson. (*Phys. Rev.*, vol. 125, pp. 912–932; February, 1962.) A theory of stochastic processes affecting spin resonance is given.

538.569.4:538.221 1890

The Theory of Ferromagnetic Resonance: Part 2—S. V. Tyablikov. (*Fiz. Tverdogo Tela.* vol. 2, pp. 2009–2018; September, 1960.) Expressions based on a temperature-difference Green's function are derived for the susceptibility tensor; some general properties are established which are independent of a specific Hamiltonian form. The energy damping of a spin system is also considered. Part 1, *Fiz. Tverdogo Tela*, vol. 2, pp. 361–368; February, 1960.

538.569.4:621.375.9:535.61–1 1891

Optical Maser Characteristics of Nd^{3+} in CaF$_2$—L. F. Johnson. (*J. Appl. Phys.*, vol. 33, p. 756; February, 1962.) Observations show that Nd^{3+} in CaF$_2$ fluoresces strongly at 0.9, 1.06 and 1.35 μ. At 77° K stimulated emission has been found in the infrared fluorescence line at 1.046 μ.

538.569.4:621.375.9:535.61–1 1892

Optical Maser Characteristics of Nd^{3+} in SrMoO$_4$—L. F. Johnson and R. R. Soden. (*J. Appl. Phys.*, vol. 33, p. 757; February, 1962.) Observations of Nd^{3+} in SrMoO$_4$ show that the three groups of lines characteristic of Nd^{3+} appear, but the precise position of the individual lines is altered slightly.

538.569.4:621.375.9:535.61–2 1893

Colloquium: Lasers and Coherence Phenomena—(*J. phys. radium*, vol. 22, pp. 827–837; December, 1961). The text is given of the following communications to the colloquium organized by the Société Française de Physique in Paris, July, 1961:

1) On a Mathematical Definition of Coherence—P. Vernotte (pp. 827–828).
2) Experimental Study of the Light Emitted by a Ruby Laser—M. Pauthier, R. Gautier, S. Deiness, and G. Amat (pp. 828–832).
3) Influence of Various Methods of Optical Excitation on the Populations of Energy Levels of Cr^{3+} Ions in Ruby—F. Gires and G. Mayer (pp. 832–834).
4) Semiconductors and their Possible Use in Lasers—C. Benoit á la Guillaume and Tric (pp. 834–836).
5) Possibilities of Semiconductor Lasers—M. Bernard and G. Duraffourg (pp. 836–837).

538.569.4:621.375.9:535.61–2 1894

Lasers and Two-Photon Processes—D. A. Kleinman. (*Phys. Rev.*, vol. 125, pp. 87–88; January, 1962.) The possibility of observing two-photon processes using a ruby laser is considered theoretically.

538.569.4:621.375.9:535.61–2 1895

Proposal for Modulating the Output of an Optical Maser—P. Kaya. (PROC. IRE, vol. 50, p. 323; March, 1962.) The strong magnetic field associated with a modulating beam is used to rotate the plane of polarization of a plane-polarized beam from another maser, which then passes through an analyzer and emerges modulated in amplitude.

538.569.4:621.375.9:535.61–2 1896

Output Power and Possible Continuous Operation of Ruby Lasers—J. C. Cook. (PROC. IRE, vol. 50, pp. 330–331; March, 1962.) Pink ruby was used in an arc-imaging furnace capable of concentrating 5.5 kw of energy as blue-green light. With starting voltages between 2.5 and 4.0 kv, average output power in a 0.7 msec pulse varied from 1 to 50 w, respectively. The threshold of continuous operation was nearly achieved.

538.569.4:621.375.9:535.61–2 1897

Scattering Losses in Optical Maser Crystals—W. Kaiser and M. J. Keck. (*J. Appl. Phys.*, vol. 33, pp. 762–764; February, 1962.) An account is given of the extinction losses resulting from the optical scattering on small foreign particles within the maser crystal in an attempt to explain the wide variation of maser threshold.

538.569.4:621.375.9:535.61–2 1898

Gaseous Optical Maser with External Concave Mirrors—W. W. Rigrod, H. Kogelnik, D. J. Brangaccio, and D. R. Herriott. (*J. Appl. Phys.*, vol. 33, pp. 743–744; February, 1962.) The construction and operation of a helium-neon optical maser is described. The discharge tube is sealed at both ends with optically flat windows at the Brewster angle to the beam axis.

539.2 1899

Nonlinear Interband and Plasma Effects in Solids—B. Lax, J. G. Mavroides and D. F. Edwards. (*Phys. Rev. Lett.* vol. 8, pp. 166–168; February, 1962.) The theory takes into account the band properties of the crystal as well as its symmetry.

GEOPHYSICAL AND EXTRATERRESTRIAL PHENOMENA

523.164 1900

A Catalogue of Radio Sources between Declinations −50° and −80°—B. Y. Mills, O. B. Slee, and E. R. Hill. (*Aust. J. Phys.*, vol. 14, pp. 497–507; December, 1961.) See 1815 of 1961.

523.164 1901

Studies in Cosmic Radio Noise at Bangalore—M. Krishnamurthi and S. Ramakrishna. (*J. Indian Inst. Sci.*, vol. 44, pp. 1–7; January, 1962.) From the results of a 28.6-Mc survey at Bangalore [see 3736 of 1961 (Bhagavantam, *et al.*)], a value of 2.37 is obtained for the spectral index of background radiation.

523.164+551.507.362.2]:550.385.4 1902

Scintillations of Radio Stars and Satellites during Intense Magnetic Disturbances—W. Kidd, H. Silverman, H. Whitney and J. Aarons. (*Nature*, vol. 193, pp. 1246–1249; March, 1962.) During periods of intense magnetic disturbance it was sometimes found that the radio-star scintillation index increased with frequency. Possible explanations are discussed.

523.164:621.396.677 1903

Interferometers for Radio Astronomy—**R. C. Glass.** (*Brit. Commun. Electronics*, vol. 9, pp. 254–259; April, 1962.) A general review of current techniques applied at several major laboratories.

523.164:621.677.3 1904

Systems for Simultaneous Image Formation with Radio Telescopes—D. J. McLean and J. P. Wild. (*Aust. J. Phys.*, vol. 14, pp. 489–496; December, 1961.) To avoid point-by-point scanning in radio astronomy, an optical and an ultrasonic method of forming instantaneous images is considered. Practical systems with useful sensitivity and resolution will require further technical development.

523.164.3 1905

The Galactic Radio Spectrum down to 19.7 Mc—M. M. Komesaroff. (*Aust. J. Phys.*, vol. 14, pp. 515–528; December, 1961.) An analysis of results of a number of surveys at frequencies between 19.7 and 1390 Mc.

523.164.3 1906

A High-Resolution Galactic Survey at 19.7 Mc—C. A. Shain, M. M. Komesaroff, and C. S. Higgins. (*Aust. J. Phys.*, vol. 14, pp. 508–515, December, 1961; plate.) Report of a survey of an extensive strip of the Southern Milky Way using a Mills Cross with 1.4° beam.

523.164.32 1907

Evidence for the Transfer of Corpuscles to Distant Parts of the Sun following a Solar Radio Burst—R. F. Mullaly. (*Aust. J. Phys.*, vol. 14, pp. 540–543; December, 1961.) Microwave and optical observations of solar bursts suggest secondary distant areas of disturbance.

523.164.32:523.5:621.396.96 1908

Forward Scatter of Radio Signals via Meteor Trials and Short-Lived Solar Radio Bursts—L. R. McNarry. (*Nature*, vol. 193, pp. 1271–1272; March, 1962.) Certain features of reported solar RF bursts may be due to the reflection of broadcast signals from meteor trails in the radiometer antenna beam.

523.164.4:621.393.677 1909

Design of Radio Telescopes for Extragalactic Surveys—G. A. Harrower. (*Canad. J. Phys.*, vol. 40, pp. 226–236; February, 1962.) Design formulas are given for ensuring that the number of sources resolved is equal to the number detected. Long wavelengths have several advantages.

523.165 1910

Hydromagnetic Waves and the Trapped Radiation: Part 3—Effects on Protons above the Proton Belt—D. G. Wentzel. (*J. Geophys. Res.*, vol. 67, pp. 485–498; February, 1962.) Previous results are extended by allowing the waves to travel at 45°, instead of parallel, to the geomagnetic field. Parts 1 and 2: 1829 of 1961.

523.165:523.75 1911

The Cosmic-Ray Flare Effect: Parts 1, 2 & 3—K. G. McCracken. (*J. Geophys. Res.*, vol. 67, pp. 423–458; February, 1962.) A new method for finding the angular dependence of the flare cosmic rays is described and applied to the anisotropic part of the solar event. The observations are used to study the interplanetary magnetic filed and to compare the relative merits of the theories of Gold and Parker.

523.3+523.4]:621.396.96 1912

A Theory of Radar Reflection from the Moon and Planets—V. A. Hughes and F. B. Daniels. (*J. Geophys. Res.*, vol. 67, pp. 892–895; February, 1962.) Comment on 3372 of 1961, and author's reply.

523.53:621.396.96 1913

Radar Observations of Meteor Echoes at a Frequency of 1300 Mc—J. S. Greenhow, H. K. Sutcliffe, and C. D. Watkins. (*Nature*, vol. 193, pp. 1036–1037; March, 1962.) During the maximum of the Geminid shower of December, 1961, 14 meteor echoes were observed at 1300 Mc. In all cases echoes were obtained from the same meteor trials at 32 Mc. These were of the "long-duration" type associated with linear electron densities greatly in excess of 10^{12}/cm.

523.745 1914

Decomposition and Comparison of Time Series of Indices of Solar Activity—F. Ward and R. Shapiro. (*J. Geophys. Res.*, vol. 67, pp. 541–554; February, 1962.)

550.38:523.152.3 1915

The Shape of the Geomagnetic Field Boundary under Uniform External Pressure—R. J. Slutz. (*J. Geophys. Res.*, vol. 67, pp. 505–513; February, 1962.) The shape of the cavity separating the geomagnetic field from the interplanetary plasma is calculated numerically for an idealized model in which the plasma pressure is assumed to be constant over the surface of the cavity.

550.38:523.75 1916

The Interaction of the Terrestrial Magnetic Field with the Solar Corpuscular Radiation—D. B. Beard. (*J. Geophys. Res.*, vol. 67, pp. 477–483; February, 1962.) A previous calculation (858 of 1961) on the shape of the interface between the solar plasma and the terrestrial magnetic field is recomputed to obtain a second-order approximation.

550.38:523.75 1917

Computation of the Boundary Surface of a Dipole Field in a Plasma by a Moment Technique—J. E. Midgley and L. Davis, Jr. (*J. Geophys. Res.*, vol. 67, pp. 499–504; February, 1962.) The cavity formed by a plasma-free dipole magnetic field in a field-free stationary plasma is determined by a numerical method. A possible extension of the theory to determine the shape of the cavity produced in the solar wind by the geomagnetic field is indicated.

550.385 1918

World-Wide Changes in the Geomagnetic Field—A. Nishida and J. A. Jacobs. (*J. Geophys. Res.*, vol. 67, pp. 525–540; February, 1962.) Current systems are drawn to depict world-wide changes and the mode of propagation of these changes is studied. They are similar to ssc and si.

550.385.2 1919

The Solar and Luni-solar Harmonic Components of Geomagnetic Variation at San Fernando—M. V. Wilkes. (*J. Atmos. Terr. Phys.*, vol. 24, pp. 73–92; February, 1962.)

550.385.3 1920

Fluctuations in the Geomagnetic Horizontal Field—A. Onwumechilli and P. O. Ogbuehi. (*J. Atmos. Terr. Phys.*, vol. 24, pp. 173–190; March, 1962.) Fluctuations in the range 1–50 γ and having durations from a few minutes to 2 hr were studied. They seem to be world-wide in their occurrence and their amplitude depends on local time and the S_q current. Other features have been deduced from the data. Suggestions for their origin are made.

550.385.37 1921

Short-Range Spatial Coherence of Geomagnetic Micropulsations—H. J. Duffus, J. A. Shand, and C. S. Wright. (*Canad. J. Phys.*, vol. 40, pp. 218–225; February, 1962.) With a separation of 10 km the coherence was high. Measurements were made in a geologically uniform region, and the Z component of the micropulsations was small.

550.385.37 1922

Auroral-Zone Geomagnetic Micropulsations with Periods of 5 to 30 Seconds—W. H. Campbell and S. Matsushita. (*J. Geophys. Res.*, vol. 67, pp. 555–573; February, 1962.) The results of one year's observations at College, Alaska, are presented and compared with other data.

550.385.4:523.165 1923

On the Earth Storms—(*Rep. Ionos. Space Res., Japan*, vol. 14, pp. 247–319; September, 1960.)

Part 1—General Introduction—T. Nagata (pp. 247–249). Some of the problems to be considered in studies of storms in the upper atmosphere and outer space of the earth are outlined.

Part 2—Stability of Solar Corpuscular Stream—A. Nishida (pp. 250–258). Collision with the interplanetary plasma causes the nonmagnetized stream to lose electrons. The resulting space charge is neutralized by the change in density of the interplanetary plasma, and the stream remains stable.

Part 3—Interaction between the Solar Corpuscular Stream and the Earth's Magnetic Field.—N. Matuura and T. Nagata (pp. 259–272). The heating of exospheric gas caused by the compression of the magnetic field during the initial phase of a storm is not sufficient to account for the main phase. The main phase might, however, result from the penetration of particles under the influence of a fluctuating magnetic field.

Part 4—Polar Magnetic Storms, with Special Reference to Relation between Geomagnetic Disturbances in the Northern and Southern Auroral Zones.—T. Nagata and S. Kokubun (pp. 273–290). Comparisons are made between the northern and southern zones on the basis of the S_D-field patterns, K indexes, and individual disturbances at magnetically conjugate points. The correlation coefficient for 10-minute-average values of disturbances (ΔH) at Baker Lake (73.7°, 315.1°, geomagnetic) and Little America (−74.0, 312.0°, geomagnetic) is 0.85.

Part 5—Interrelations among the Upper Atmosphere Disturbance Phenomena over the Polar Regins.—T. Oguti (pp. 291–300). Observations at Syowa (69°00′S, 39°35′E) during the period January, 1959–January, 1960 are used to examine the detailed correlations between geomagnetic disturbance, visual auroras, and ionospheric blackouts or sporadic E.

Part 6—Energy and Flux of Corpuscular Streams Impinging the Earth's Atmosphere.—T. Tohmatsu and T. Nagata (pp. 301–319). An examination is made of the energy and flux of the corpuscular streams responsible for the ionospheric blackouts in the polar cap, the unusual displays and ionospheric effects in the auroral zone, and the red aurora observed at lower latitudes.

550.385.4:523.745 1924

Statistics of Geomagnetic Storms and Solar Activity—T. Saemundsson. (*Monthly Notices Roy. Astron. Soc.*, vol. 123, no. 4, pp. 299–316; 1962.)

551.507.362.2 1925

An Economical Satellite Launching Technique for Conducting Radio Research in Space—J. D. Nicolaides. (*J. Brit. IRE*, vol. 23, pp. 205–208; March, 1962.) "A simple and inexpensive launching technique for economical radio research is described which employs an aircraft and rocket combination to place a 20-lb satellite into orbit. The paper reviews the progress to date and indicates performance potential."

551.507.362.2 1926

Satellite 1958 δ_2 Data Analysis—D. G. Parkyn. (*J. Geophys. Res.*, vol. 67, pp. 611–618; February, 1962.) An analysis of data shows a temperature peak at 200 km and an 8-h density oscillation.

551.507.362.2 1927

Experimental Evidence for the Presence of Helium Ions based on Explorer VIII Satellite Data—R. E. Bourdeau, E. C. Whipple, Jr., J. L. Donley, and S. J. Bauer. (*J. Geophys. Res.*, vol. 67, pp. 467–475; February, 1962.)

551.507.362.2:523.164 1928

Orbiting Ultraviolet System will Map Stars and the Sky's Radiant Intensity—(*Electronics*, vol. 35, pp. 22–23; February, 1962.) An outline of camera calibration equipment and the command and telemetry systems for Project Celoscope.

551.507.362.2:550.385 1929

Oribital Acceleration of Satellites during Geomagnetic Disturbance—K. D. Cole. (*Nature*, vol. 194, pp. 42, 75; April, 1962.) Approximate analysis is developed to show that joule heating of the lower reaches of the ionosphere by geomagnetic currents is a major factor in the modulation of thermospheric densities which causes fluctuations in the orbital acceleration of satellites.

551.507.362.2:621.317.794 1930

Infrared Radiometric Instruments on TIROS II—R. W. Astheimer, R. DeWaard, and E. A. Jackson. (*J. Opt. Soc. Amer.*, vol. 51, pp. 1386–1393; December, 1961.)

551.507.362.2:621.317.794 1931

TIROS II Radiation Experiment and its Physical Significance—R. A. Hanel and D. Q. Wark. (*J. Opt. Soc. Amer.*, vol. 51, pp. 1394–1399; December, 1961.) The five-channel radiometer which scans the earth by satellite roatation is described. A map of the radiation received by the channel sensitive to 8–12-μ wavelength is compared with a conventional weather chart.

551.510.535 1932

Law of Electric Conduction for Waves in the Ionosphere—T. Watanabe. (*J. Atmos. Terr. Phys.*, vol. 24, pp. 117–125; February, 1962.) "The law of electric conduction has been derived as for transverse waves propagated along a strong external magnetic field in a slightly ionized gas. The results have been applied to waves in the ionosphere."

551.510.535 1933

A Note on the Group Refractive Index of the Ionosphere for Zero Collisional Frequency—Y. S. N. Murty and S. R. Khastgir. (*J. Atmos. Terr. Phys.*, vol. 24, pp. 141–143; February, 1962.) A difference between the general expressions for the group refractive index derived by Unz (1928 of 1961) and Murty and Khastgir (2965 of 1961) is due to an error in sign in the former.

551.510.535 1934

Recombination in the Upper Ionosphere—O. Burkard. (*J. Atmos. Terr. Phys.*, vol. 24, pp. 145–153; March, 1962.) At sunrise and before noon, the loss of electrons in the F layer will occur as a result of dissociative recombination of NO^+. The recombination coefficient will increase linearly with temperature and the rate of production of electrons will be proportional to $\alpha_0 TN_e^2$.

551.510.535 1935

Lunar Daily Variation of Horizontal Drifts in the Ionosphere at Waltair—K. V. V. Ramana and B. R. Rao. (*J. Atmos. Terr. Phys.*, vol. 24, pp. 220–221; March, 1962.) The amplitudes and phases of the 12-hourly harmonics of the drift in the E and F regions are given for the four seasons.

551.510.535 1936

The Phase Speed of a Travelling Disturbance in the F Region of the Ionosphere and its Comparison with Group Velocity—L. H. Heisler and J. D. Whitehead. (*Aust. J. Phys.*, vol. 14, pp. 481–488; December, 1961.) The phase speed of an F-region disturbance is observed to be about half the group velocity of 10 km/min.

551.510.535 1937

On the Mean Temporal Variations of Electron Density at a Fixed Height in the F Region—A. J. Hirsh and R. W. Knecht. (*J. Geophys. Res.*, vol. 67, pp. 595–600; February, 1962.) A sunrise dip in the diurnal variation of div (*NV*) deduced from Puerto Rico data may possibly be explained by a reversal in the E-W ionospheric wind. The diurnal variations of the F layer may be due to loss rate changes resulting from the presence of NO between sunrise and sunset.

551.510.535:523.75 1938

Increases of Ionization in the F2 Layer and Solar Corpuscular Radiation—C. J. Waddington. (*Nature*, vol. 193, pp. 1272–1273; March, 1962.) Every reported large increase in F2 ionization during a flare has been associated with an increase in corpuscular radiation; examination of further data should lead to an explanation of corpuscular acceleration processes.

551.510.535:523.75 1939

A Theory of S.F.E. Current Systems—T. Rikitake and T. Yukutake. (*J. Atmos. Terr. Phys.*, vol. 24, pp. 93–106; February, 1962.) A study of the development of the current system of the solar-flare effect after a sudden increase in the electrical conductivity of the ionosphere facing the sun, based on the theory of electromagnetic induction.

551.510.535:523.75 1940

Information on the Ionizing Radiation of Solar Flares from the Ionospheric Absorption Effects—J. Taubenheim. (*J. Atmos. Terr. Phys.*, vol. 24, pp. 191–201; March, 1962.) The additional ionization is produced in a thin layer at 70–75-km height and the attachment coefficient is 2×10^{-3} sec^{-1}. The radiation flux deduced from the ionospheric changes agrees well with rocket measurements. The spectrum of the ionizing radiation is probably mainly line emission near 2*Å*.

551.510.535:550.37 1941

The Equatorial Sporadic-E Layer and the Electrojet—K. M. Kotadia. (*J. Atmos. Terr. Phys.*, vol. 24, pp. 211–218; March, 1962.) *Es* data from three chains of stations near the magnetic equator, but at different longitudes, have been studied, and from them it has been possible to deduce information about the extent of the electrojet, its seasonal changes and its variations with sunpsot number and longitude.

551.510.535:550.385 1942

A Source of Energy for the Ionosphere—K. D. Cole. (*Nature*, vol. 194, p. 75; April, 1962.) Joule heating by electric currents associated with geomagnetic variations is normally sufficient to account for the heat flux in the low-altitude ionosphere. See also 1929 above.

551.510.535:550.385 1943

The Relationship between f_0F2 and Magnetic Phenomena—J. W. King and C. Graham. (*J. Atmos. Terr. Phys.*, vol. 24, pp. 107–115; February, 1962.) A general seasonal relation between f_0F2 and A_p is shown to be similar over a wide range of latitudes and also for both daytime and nighttime data.

551.510.535:551.307.362.1 1944

Analysis of Probe Characteristics in Drifting Plasma—T. Dote, K. Takayama, and T. Ichimiya. (*J. Phys. Soc. Japan*, vol. 17, pp. 174–183; January, 1962.) For a spherical Langmuir probe moving relatively to a plasma the ion sheath is deformed. Positive-ion densities determined from rocket measurements in the ionosphere for certain sheath configurations have been compared with simultaneous observations of density deduced from $h'(f)$ curves. Agreement is good.

551.510.535:551.507.362.2 1945

Satellite Observations of Electron Content at the Magnetic Equator—L. J. Blumle and W. J. Ross. (*J. Geophys. Res.*, vol. 67, pp. 896–897; February, 1962.) Daytime values of electron content near 4×10^{17}/m^2 are obtained.

551.510.535:551.507.362.2 1946

Variations of Scale Height in the Upper Atmosphere—D. G. King-Hele. (*Nature*, vol. 194, pp. 39–40; April, 1962.) Analysis of satellite orbital data suggests a decrease of the density scale height in the upper atmosphere from 1958 to 1961 which is attributed to a drop of 500°K in the average temperature at 250–400 km.

551.510.535:551.362.2:621.391.812.3 1947

The Heights of Ionospheric Irregularities in the Auroral Zone—R. P. Basler and R. N. DeWitt. (*J. Geophys. Res.*, vol. 67, pp. 587–593; February, 1962.) 20-Mc signals from Sputnik III were received at points spaced by 19 km. The heights of irregularities giving scintillation were found to range from 250 to 650 km, with occasional higher values.

551.510.535:621.3.087.4:621.318.57 1948

A Sequence Switching Unit for Measurement of Ionospheric Drift—S. C. Bose. (*J. Inst. Telecommun. Engrs., India*, vol. 17, pp. 255–264; November, 1961.) In a modification of the three-receiver system, a unit switches the input of a single receiver between three antennas, the output signal of each antenna being displayed simultaneously with vertical separation on a CRO.

551.510.535:621.391.812.63 1949

A Study of F2-Layer Effects as Observed with a Doppler Technique—K. Davies, J. M. Watts, and D. H. Zacharisen. (*J. Geophys. Res.*, vol. 67, pp. 601–609; February, 1962.) Frequency changes in the radio waves arriving at Boulder, Colorado, from WWV are measured. The frequency dependence of these changes is shown to give information about heights of the ionospheric disturbances.

551.510.535:621.396.96 1950

A New Method of Space Exploration by Radar using incoherent Scattering—T. Laaspere. (*Commun. and Electronics*, no. 58, pp. 557–560; January, 1962.) Discussion of incoherent scattering by spatial fluctuations in electron density, and a review of theoretical and experimental results. Emphasis is on the properties of the ionosphere.

551.510.536 1951

Stability of a Simplified Geocyclotron Model—J. S. Lew. (*J. Geophys. Res.*, vol. 67, pp. 515–524; February, 1962.) A treatment of the phase stability of the geocyclotron, a mechanism for acclerating electrons in the outer ionosphere. See 3508 of 1960 (Helliwell and Bell).

551.510.62 1952

The Radio Refractive Index of Air—B. R. Bean. (PROC. IRE, vol. 50, pp. 260–273; March, 1962.) A review paper containing fifty-one references. The constants in the classical Debye expression for the radio refractive index are discussed together with the errors incurred in using standard meteorological data. Model atmospheres and radio climatology are also discussed.

551.594.6 1953

Sferic Observations of the Severe Weather on May 19, 1960—C. A. Samson and R. F. Linfield. (*J. Geophys. Res.*, vol. 67, pp. 627–635; February, 1962.) Records obtained with the Ephi system [2609 of 1961 (Hefley, *et al.*)] are presented and discussed in relation to certain weather and propagation factors.

551.594.6:621.391.82 1954

Diurnal Power Variations of the Earth-Ionosphere Cavity Modes and their Relationship to World-Wide Thunderstorm Activity—M. Balser and C. A. Wagner. (*J. Geophys. Res.*, vol. 67, pp. 619–625; February, 1962.)

MATERIALS AND SUBSIDIARY TECHNIQUES

535.215:537.533.8 1955

Secondary Electron Emission of Caesium-Germanium Films of Different Composition—G. Appelt. (*Ann. Phys.* (*Lpz.*), vol. 9, pp. 30–43; December, 1961.)

535.215:546.23 1956

Quenching Effects and Negative Photoconductivity in Amorphous Selenium—J. Dresner. (*J. Chem. Phys.*, vol. 35, pp. 1628–1635; November, 1961.) Measurements of optical quenching and negative photoconductivity in evaporated layers of amorphous Se were followed by a study of the distribution of trapping states using thermally stimulated currents and space-charge-limited currents.

535.215:546.47'221 1957

Theory of the Anomalous Photovoltaic Effect of ZnS—G. F. Neumark. (*Phys. Rev.*, vol. 125, pp. 838–845; February, 1962.) The theory proposed depends on the internal fields arising from spontaneous polarization.

535.215:546.48'221 1958

Ohmic-Contact Photovoltage in CdS—W. Ruppel. (*Helv. Phys. Acta*, vol. 34, pp. 790–795; December, 1961. In English.) The open-circuit photovoltage of CdS crystals with In, Au and Cu electrodes was measured as a function of light intensity for illumination by white and blue light.

535.215:546.48'221 1959

Dielectric Breakdown in Cadmium Sulphide—R. Williams. (*Phys. Rev.*, vol. 125, pp. 850–854; February, 1962.) Experimental values of the breakdown field are of the order of 10^6 v/cm. Breakdown does not involve impact ionization and is apparently due to internal field emission.

535.215:546.77 1960

Field Dependence of Photoelectric Emission from Molybdenum—R. C. Jaklevic and D. W. Juenker. (*J. Appl. Phys.*, vol. 33, pp. 562–568; February, 1962.) Photoelectric emission from a 5-mil single-crystal wire was measured at 1000°K with accelerating fields of 0.8–142 kv/cm. Above 3.6 kv/cm the data are in good agreement with Fowler-Schottky theory.

535.215:546.817–31 1961

Electrical Conductivity and Photoconductivity of Lead Oxide Layers Treated with Sulphur, Selenium and Tellurium—P. P. Konorov and A. N. Sokolov. (*Fiz. Tverdogo Tela*, vol. 2, pp. 2240–2242; September, 1960.)

535.37:537.226 1962

The Photodielectric Effect in ZnS-Cu, Co Phosphors—F. I. Vergunas and G. M. Malkin.

(*Fiz. Tverdogo Tela*, vol. 2, pp. 2322–2329; September, 1960.) The photodielectric effect in the frequency range 200 cps – 5 Mc is attributed to a grain-conduction mechanism.

535.37:546.47'221 1963
Fluorescence of Cubic ZnS:Cl Crystals—H. Samelson and A. Lempicki. (*Phys. Rev.*, vol. 125, pp. 901–909; February, 1962.)

535.376:546.47'221 1964
Electroluminescence in Zinc Sulphide—J. L. Gillson, Jr., and F. J. Darnell. (*Phys. Rev.*, vol. 125, pp. 149–158; January, 1962.) Microscopic observations of electroluminescent crystals show that emission originates from discrete narrow lines and spots within the material. A model involving linear physical defects is proposed to explain these lines and their variation with voltage, frequency and phase of the applied field.

535.376:546.48'47'221 1965
Capacitance Variation and Electrophotoluminescence of an Optically Excited (Zn, Cd)S Phosphor under the Influence of Electric Constant-Field Pulses—F. Matossi, H. Gutjahr, and D. Siebert. (*Z. Naturforsch.*, vol. 16a, pp. 1391–1393; December, 1961.)

537.226:621.319.2:535.376 1966
Parallel Investigation of Depolarization and Electroluminescence of ZnS Photoelectrets—V. M. Fridkin, A. N. Bogatyrev, and E. V. Brakhman. (*Fiz. Tverdogo Tela*, vol. 2, pp. 2185–2190; September, 1960.) The effect of electroluminescence on depolarization is examined. The experimental method and results are briefly discussed.

537.227:538.569.4 1967
Electron Spin Resonance in γ-Irradiated Triglycine Sulphate—D. W. Ovenall and K. A. Müller. (*Helv. Phys. Acta*, vol. 34, pp. 786–790; December, 1961. In English.) Analysis of spin resonance spectra above and below the Curie point.

537.227:546.431'824–31 1968
Dielectric Properties of Finely Dispersed Barium Titanate—A. L. Khokadov. (*Fiz. Tverdogo Tela*, vol. 2, pp. 2126–2130; September, 1960.) An investigation of the dielectric properties of heterogeneous systems, relating to $BaTiO_3$ particles of size 1–20 μ in a resin binder.

537.227:546.431'824–31 1969
Theory of the Dielectric Constants of Barium Titanate—W. Kinase. (*J. Phys. Soc. Japan*, vol. 17, pp. 70–84; January, 1962.) Calculations are based on a molecular model taking account of the shift of Ti ions only.

537.227:621.318.57 1970
Switching Properties in Ferroelectrics of the Family $Bi_4Ba_{m-2}Ti_{m+1}O_{3(m+2)}$—P. H. Fang and E. Fatuzzo. (*J. Phys. Soc. Japan*, vol. 17, p. 238; January, 1962.) Switching characteristics of three forms of the material are compared with those of $BaTiO_3$.

537.228.1 1971
The Vibration Characteristics of an Ultrasonic Crystal—H. Goetz and E. Breitfelder. (*Z. angew. Phys.*, vol. 13, pp. 565–569; December, 1961.) Two modes of vibration of a circular disk are investigated experimentally by measuring its impedance at resonance.

537.228.1 1972
Deformation of Piezoelectric Plates—H. S. Paul. (*Appl. Sci. Res.*, vol. B9, pp. 359–373; 1962.) General equations in two-dimensional statical problems of piezoelectricity have been derived by introducing the Airy stress function and the electric potential. Problems of lateral bending by shearing forces at one edge and deformation due to uniformly distributed forces are considered.

537.228.1:546.431'824–31 1973
Some Features of the Piezoelectric Effect in Barium Titanate—Z. A. Shamro. (*Fiz. Tverdogo Tela*, vol. 2, pp. 2085–2088; September, 1962.) Measurements have been made of the residual piezoelectric effect under static conditions, using a high-temperature polarization method. The existence of a number of qualitatively different components of the piezoelectric modulus has been established.

537.228.1:546.431'824–31 1974
The Coupling of Radial Resonance Modes of Vibrating Circular $BaTiO_3$ Disks with Resonance Modes of Different Type on Changing the Geometric Dimensions—L. Walther and G. Langensiepen. (*Hochfrequenz. und Elektroak.*, vol. 70, pp. 211–214; December, 1961.)

537.228.1:549.514.51 1975
Theory of the Optical Properties of Quartz in the Infrared—D. A. Kleinman and W. G. Spitzer. (*Phys. Rev.*, vol. 125, pp. 16–30; January, 1962.)

537.311.31 1976
Determination of the Mean Free Path of Conduction Electrons—R. Kleinberg and F. J. Blatt. (*Ann. Phys.* (*Lpz.*), vol. 9, pp. 62–64; December, 1961. In English.) The assumptions made by Scheffers (148 of 1957) are shown to be incorrect, and the agreement of his theory with experimental results obtained on Au, Ag and Cu is fortuitous.

537.311.33 1977
Double Injection in Insulators—M. A. Lampert. (*Phys. Rev.*, vol. 125, pp. 126–141; January, 1962.) The simultaneous injection of electrons and holes into an insulator is analyzed taking into account that the lifetimes for the electrons and holes are different and vary with injection level. Assuming charge neutrality; a solution is obtained for a simple insulator model.

537.311.33 1978
Two-Phonon Transitions in the Impurity Conduction in Semiconductors—J. Mycielski. (*Phys. Rev.*, vol. 125, pp. 46–51; January, 1962.) Numerical data are given for *n*- and *p*-type Si and Ge. Two-phonon transitions can play a role in impurity conduction in materials with low mobility of carriers and low impurity concentration.

537.311.33 1979
Theory of Impurity-Band Conduction in Semiconductors. An Approach to Random-Lattice Problem—T. Matsubura and Y. Toyozawa. (*Progr. Theoret. Phys.*, vol. 26, pp. 739–756; November, 1961.) The impurity-band problem in semiconductors is formulated in terms of a Green's function, the calculation of which is carried out by a graphical method.

537.311.33 1980
The Boundary Conditions in the Theory of Surface Conductivity of Semiconductors—G. Ciobanu. (*Z. Phys.*, vol. 165, pp. 184–201; November, 1961.) Calculations cover the cases of 1) a plane semiconductor surface, and 2) a semiconductor wire with circular cross section.

537.311.33 1981
Ionicities, Effective Charges and Electron Mobilities in Mineral Semiconductor Compounds—J. P. Suchet. (*J. Phys. Chem. Solids*, vol. 21, pp. 156–171; December, 1961. In French.) A further study of the influence of chemical bonds on semiconductor properties. See also 1552 of 1961.

537.311.33 1982
Excitons at the L Absorption Edge in Zinc-Blende-Type Semiconductors—M. Cardona and G. Harbeke. (*Phys. Rev. Lett.*, vol. 8, pp. 90–91; February, 1962.)

537.311.33 1983
Observation of d Bands in 3-5 Semiconductors—H. R. Philipp and H. Ehrenreich. (*Phys. Rev. Lett.*, vol. 8, pp. 92–94; February, 1962.)

537.311.33 1984
Electronic States on Dislocations in Semiconductors—V. Celli, A. Gold, and R. Thomson. (*Phys. Rev. Lett.*, vol. 8, pp. 96–97; February, 1962.) The strain fields associated with dislocations in semiconductors can give rise to acceptor levels near the top of the gap; these may have a significant influence on the electronic properties of *n*-type material.

537.311.33 1985
Diffusion of Impurities in a Thin Semiconductor Slab—E. D. Fabricius. (*J. Appl. Phys.*, vol. 33, pp. 753–754; February, 1962.) By choosing suitable boundary conditions, the equation representing diffusion of impurities into a solid crystal can be extended to the case for a thin slab.

537.311.33 1986
Diffusion of Impurities in the Semiconductor Melt—S. Tauchi. (*J. Phys. Soc. Japan*, vol. 17, pp. 102–113; January, 1962.) An analysis of a new double-diffusion process for the production of *n-p-n* or *p-n-p* junctions. See *Solid-State Electronics*, vol. 2, pp. 216–221; May, 1961.

537.311.33 1987
Synthesis and Investigation of Vitreous Oxide Semiconductors in Systems of the Type $VO_{2.5}$—$PO_{2.5}$—RO_x—L. A. Grechanik, N. V. Petrovych, and V. G. Karpechenko. (*Fiz. Tverdogo Tela*, vol. 2, pp. 2131–2139; September, 1960.)

537.311.33 1988
A New Method of Determining the Effective Cross-Sections of Local Centres—É. I. Adirovich. (*Fiz. Tverdogo Tela*, vol. 2, pp. 2248–2251; September, 1960.) The method is based on a unipolar excitation of the crystal, *i.e.*, generation of nonequilibrium carriers only in the majority-conduction band.

537.311.33 1989
The Theory of the Deformation Potential for Semiconductors with Complex Band Structure—G. L. Bir and G. E. Pikus. (*Fiz. Tverdogo Tela*, vol. 2, pp. 2287–2300; September, 1960.) An operator is constructed for the interaction of electrons with long-wavelength acoustic and optical phonons, and the transition probabilities are calculated. The results are applied to the scattering of holes in *p*-type Ge.

537.311.33 1990
The Theory of the Work per Electron-Hole Pair in Group IV Semiconductors—W. Czaja. (*Helv. Phys. Acta*, vol. 34, pp. 760–764; December, 1961. In German.) The relation between the energy expended in the production of electron-hole pairs and the width of the forbidden band discussed in 3123 of 1961 (Baldinger and Czaja) is investigated on a different basis.

537.311.33 1991
Semiconducting Compounds of Skutterudite Structure—F. Hulliger. (*Helv. Phys. Acta*, vol. 34, pp. 782–786; December, 1961.

In German.) Preliminary report of investigations of CoAs$_3$ and related compounds. See also 1597 of May.

537.311.33:537.29 1992
Theory of Field Emission from Semiconductors—R. Stratton. (*Phys. Rev.*, vol. 125, pp. 67–82; January, 1962.) The theory allows for the difference between the effective and free electron masses. The emission current for the range intermediate between thermionic and field emission is discussed. The field emission currents from the conduction and valence bands are both considered, and numerical results are given for Ge which are qualitatively consistent with experiment.

537.311.33:537.32:538.63 1993
Thermomagnetic Phenomena in Semetals in a Strong Magnetic Field—A. I. Ansel'm and B. M. Askerov. (*Fiz. Tverdogo Tela*, vol. 2, pp. 2310–2321; September, 1960.) The effect on thermomagnetic phenomena of the quantization of conduction electrons in a magnetic field is considered. The Nernst coefficient and the variations of thermoelectric power with magnetic field are calculated in the quantum-mechanical limit.

537.311.33:538.612 1994
Voigt Effect in Semiconductors—M. Cardona. (*Helv. Phys. Acta*, vol. 34, pp. 796–801; December, 1961. In English.) The investigation of the band structure of semiconductors with the aid of magneto-optical effects is discussed. The free-carrier and interband Voigt effects are calculated.

537.311.33:538.63 1995
Optical Absorption Spectrum of Hydrogenic Atoms in a Strong Magnetic Field—H. Hasegawa and R. E. Howard. (*J. Phys. Chem. Solids*, vol. 21, pp. 179–198; December, 1961.) Theoretical treatment of magneto-optical absorption in semiconductors.

537.311.33:538.63 1996
Microwave Measurements on the Magnetoresistance Effect in Semiconductors—R. Koike and H. E. M. Barlow. (PROC. IRE, pt. B, vol. 109, pp. 137–144; March, 1962.) The experimental results demonstrate the existence of a magnetoresistance effect at 10 Gc. The technique enables carrier mobility to be determined. Preparation of semiconducting 10^3 Å thick is described.

537.311.33:538.632 1997
The Hall Effect in a 'Many-Valley' Semiconductor—S. H. Koenig. (*Helv. Phys. Acta*, vol. 34, pp. 765–770; December, 1961. In English.) In a multivalley semiconductor the measured Hall field can be a function of the geometry of the specimen and the intervalley scattering rate.

537.311.3/3+537.311.31]:539.23 1998
Investigation of the Electrical Properties and the Scintillation Effect of Certain Thin Metallic or Semiconducting Films—C. Uny. (*Ann. Phys.* (*Paris*), vol. 6, pp. 1275–1325; September/October, 1961. Plates.) The investigation covers conductivity and noise measurements on Au, Ag, Cu and polycrystalline and amorphous Ge films (see 1684 of 1960 and back references). Differences in the effects observed in the various elements are explained.

537.311.33:546.23 1999
The Effect of Thallium on the Conductivity of Halogen-Doped Selenium—H. P. Hempel, H. Lauckner and H. Thumann. (*Z. Naturforsch.*, vol. 16a, pp. 1402–1403; December, 1961.)

537.311.33:[546.28+546.289 2000
A Mechanism for the Introduction of Recombination Centres into Germanium and Silicon during Low-Temperature Quenching—L. S. Milevskiĭ. (*Fiz. Tverdogo Tela*, vol. 2, pp. 2218–2227; September, 1960.) The effect of quenching from temperature of 250–600°C on the lifetime of minority carriers in n-type Ge and Si is investigated. Results confirm that the formation of recombination centers is due to a movement of dislocations away from the impurity atmosphere.

537.311.33:[546.28+546.289 2001
Photon-Assisted Tunnelling in Silicon and Germanium Esaki Junctions—A. G. Chynoweth, R. A. Logan, and D. E. Thomas. (*Phys. Rev.*, vol. 125, pp. 877–881; February, 1962.) Inflections in the I/V characteristics of Esaki junctions at low temperatures are ascribed to phonon cooperation in indirect tunneling transitions. Several features in Si and Ge junctions are identified, and other features, less well understood, are discussed.

537.311.33:[546.28+546.289]:539.12.04 2002
Low-Temperature Length Change Measurements of Electron-Irradiated Germanium and Silicon—F. L. Vook. (*Phys. Rev.*, vol. 125, pp. 855–861; February, 1962.)

537.311.33:546.28 2003
Controlled Etching of Silicon in the HF-HNO$_3$ System—D. L. Klein and D. J. D'Stefan. (*J. Electrochem. Soc.*, vol. 109, pp. 37–42; January, 1962.) An examination of the important variables involved in controlled chemical etching and their effects on the kinetics of Si dissolution.

537.311.33:546.28 2004
Junction Delineation in Silicon—H. Robbins. (*J. Electrochem. Soc.*, vol. 109, pp. 63–64; January, 1962.) Reproducible delineation can be obtained in the absence of strong illumination provided the reactions occur in the presence of strong HF.

537.311.33:546.28 2005
Influence of Heat Treatment of Silicon on the Lifetime of Nonequilibrium Charge Carriers—V. A. Atsarkin and E. Z. Mazel'. (*Fiz. Tverdogo Tela*, vol. 2, pp. 2089–2094; September, 1960.) A report and discussion of quenching experiments carried out in the temperature range 400–700°C. The formation of recombination centers is determined by the annealing process in quenched samples as well as by the heat treatment.

537.311.33:546.28 2006
The Effect of Quenching on the Minority-Carrier Lifetime in Silicon—L. S. Milevskiĭ. (*Fiz. Tverdogo Tela*, vol. 2, pp. 2158–2160; September, 1960.)

537.311.33:546.28 2007
Some Measurements of the Surface Properties of Silicon by D.C., A.C. and Pulsed Field Effects—B. R. Marathe. (*Proc. Phys. Soc.* (*London*), *A*, vol. 79, pp. 503–506; March, 1962.) Measurements over a wide temperature range are reported. Results of the pulse measurements are used to interpret the ac field-effect curve.

537.311.33:546.28 2008
Surface-State Levels in Silicon as Revealed by the Pulsed Field-Effect Technique—J. A. Champion. (*Proc. Phys. Soc.* (*London*), *A*, vol. 79, pp. 662–665; March, 1962.) The energy levels of surface states on Si appear to be highly dependent on the etches used.

537.311.33:546.28 2009
Coherent Oscillation from Forward-Biased Point Contact on Silicon Single Crystals—M. Kikuchi. (*J. Phys. Soc. Japan*, vol. 17, p. 240; January, 1962.) Stable oscillations in the range 1–20 Mc are observed with n-type crystals of resistivity 1.2–330 Ω cm·at low bias voltages. The frequency and waveform are dependent on voltage; the amplitude only weakly so. Modulated oscillations can occur.

537.311.33:546.28 2010
Volume Recombination of Current Carriers in n-Type Silicon containing Radiation-Induced Structural Defects—G. N. Galkin, N. S. Rytova, and V. S. Vavilov. (*Fiz. Tverdogo Tela*, vol. 2, pp. 2025–2030; September, 1960.) Capture cross sections for electrons and holes determined from lifetime measurements are at variance with Wertheim's results. The level at -0.16 ev is identified as an acceptor level, in agreement with data of Watkins, *et al.* (4089 *h* of 1959).

537.311.33:546.28:541.135 2011
Inversion Layers in Silicon at the Boundary with an Electrolyte—H. U. Harten. (*Z. Naturforsch.*, vol. 16a, p. 1401; December, 1961.) Investigation of surface conductivity in n- and p-type Si specimens immersed in electrolyte. See also *Z. Naturforsch.*, vol. 16a, pp. 459–466; May, 1961.

537.311.33:546.28:621.387.462 2012
The Release of Avalanche Discharges in Silicon p-n-Type Barrier Layers under Particle Irradiation—I. Ruge. (*Z. Naturforsch.*, vol. 16a, pp. 1398–1400; December, 1961.) Measurements on Zener diodes are analyzed and the suitability of the junctions for particle counters is discussed.

537.311.33:546.289 2013
Observation of Coherent Oscillation in Germanium—M. Kikuchi and Y. Abe. (*J. Phys. Soc. Japan*, vol. 17, pp. 241–242; January, 1962.) Oscillations are excited in high-resistivity Ge by applying a pulsed electric field and high-intensity light beam. The frequency is about 100 kc increasing with light intensity.

537.311.33:546.289 2014
Solid Solubility of Gold in Germanium—A. S. Syed. (*Canad. J. Phys.*, vol. 40, pp. 286–288; February, 1962.) The solidus curve shows a maximum at about 30°K below the melting point of Ge.

537.311.33:546.289 2015
Influence of a Copper-Impurity Atmosphere at Dislocations in Germanium on Recombination—S. G. Kalashnikov and A. K. Mednikov. (*Fiz. Tverdogo Tela*, vol. 2, pp. 2058–2065; September, 1960.)

537.311.33:546.289 2016
Diffusion of Antimony in Germanium Alloyed with Aluminum—I. P. Akimchenko and L. S. Milevskiĭ. (*Fiz. Tverdogo Tela*, vol. 2, pp. 2109–2216; September, 1960.) Measurements in the temperature range 650–930°C are reported. The Sb diffusion coefficient decreased with increase of Al concentration above a value of 5×10^{17} atoms/cm^2.

537.311.33:546.289 2017
Effect of Dislocations on Self-Diffusion in Germanium—H. Widmer. (*Phys. Rev.*, vol. 125, pp. 30–32; January, 1962.)

537.311.33:546.289 2018
Point Defects in p-Type Germanium as Introduced by Deformation, Quenching, and Electron Bombardment—J. N. Hobstetter and C. A. Renton. (*J. Appl. Phys.*, vol. 33, pp. 600–605; February, 1962.) Different treatments of 5-Ω cm p-type Ge yielded markedly different numbers of carriers. The results are accounted for by an energy-level scheme similar to that of James and Lark-Horovitz.

537.311.33:546.289:539.12.04 2019

On the Change of Surface States of Germanium by Irradiation—K. Komatsubara. (*J. Phys. Soc. Japan*, vol. 17, pp. 62–69; January, 1962.) The change is observed by displaying the field-effect patterns, showing reverse current as a function of voltage on a CRO. Results indicate that on irradiation either a new level appears or the level density increases.

537.311.33:546.289:621.391.822 2020

The $1/f$ Noise on Surface-Doped Germanium Filaments—P. O. Lauritzen and J. F. Gibbons. (*J. Appl. Phys.*, vol. 33, pp. 758–759; February, 1962.) The results of a series of experiments with surface-doped Ge filaments are presented. These include the measurement of the frequency spectrum, noise correlation and sensitivity of $1/f$ noise level to the electric field strength, temperature and magnetic field.

537.311.33:546.3–1'289'28 2021

Thermal Conductivity of Ge-Si Alloys at High Temperatures—B. Abeles, D. S. Beers, G. D. Cody, and J. P. Dismukes. (*Phys. Rev.*, vol. 125, pp. 44–46; January, 1962.)

537.311.33:546.3–1'289'28:539.23 2022

Epitaxial Silicon-Germanium Alloy Films on Silicon Substrates—K. J. Miller and M. J. Grieco. (*J. Electrochem. Soc.*, vol. 109, pp. 70–71; January, 1962.) Alloys with up to 30 atomic per cent Ge have been deposited epitaxially on Si substrates by the simultaneous vapor-phase reduction of $SiCl_4$ and $GeCl_4$.

537.311.33:546.48'19 2023

Some Properties of Cd_3As_2—N. Sexer. (*J. phys. radium*, vol. 22, pp. 807–810; December, 1961.) The study of resistivity, Hall effect and thermoelectric power of Cd_3As_2 as a function of the carrier concentration has shown that the electron gas is practically degenerate, and that electron scattering by acoustic phonons predominates at room temperature.

537.311.33:[546.48'241+546.289 2024

Dielectric-Constant Behaviour near Band Edges in CdTe and Ge—D. T. F. Marple and H. Ehrenreich. (*Phys. Rev. Lett.*, vol. 8, pp. 87–89; February, 1962.)

537.311.33:546.681'18:538.569.4 2025

Nuclear Magnetic Resonance in Gallium Phosphide—M. J. Weber. (*J. Phys. Chem. Solids*, vol. 21, pp. 210–218; December, 1961.)

537.311.33:546.681'19 2026

Electrical Properties of Li in GaAs—C. S. Fuller and K. B. Wolfstirn. (*J. Appl. Phys.*, vol. 33, pp. 745–746; February, 1962.) Measurements of the effect of Li diffused into undoped GaAs are presented. The p-type behavior is explained by diffusion of Li interstitials to the surface.

537.311.33:546.681'19 2027

Heat Treatment of n-Type GaAs by Radiant Energy—T. S. Kinsel and T. E. Seidel. (*J. Appl. Phys.*, vol. 33, pp. 767–769; February, 1962.) Radiant heating techniques have been applied in an attempt to prevent n-type GaAs being converted to p-type material during high-temperature processing.

537.311.33:546.681'86 2028

The Effect of Arsenic Pressure on Impurity Diffusion in Gallium Arsenide—L. J. Vieland. (*J. Phys. Chem. Solids*, vol. 21, pp. 318–320; December, 1961.)

537.311.33:546.682'86 2029

Microwave-Induced Carrier Multiplication in Indium Antimonide—K. Rose. (*J. Appl. Phys.*, vol. 33, pp. 761–762; February, 1962.) Microwave transmission through InSb at 80°K has been measured. The results indicate that the transmission is limited for input power levels >100 w.

537.311.33:[546.863'151+546.873'151 2030

The Electrical Resistivity of Solid and Liquid Tri-iodides of Antimony and Bismuth—G. Fischer. (*Helv. Phys. Acta*, vol. 34, pp. 827–833; December, 1961. In English.) SbI_3 and BiI_3 are found to be semiconductors with high resistivities at room temperature and with large energy gaps.

537.311.33:621.317.3 2031

Surface and Dimensional Corrections for the Measurement of Minority-Carrier Lifetime in Semiconductors—C. Fritzsche. (*Z. angew. Phys.*, vol. 13, pp. 576–580; December, 1961.) The influence of surface recombination and the thickness of the specimen on the results of lifetime measurements by the methods of Valdes (741 of 1953) and Stevenson and Keyes (2008 of 1955) is discussed with reference to experimental results.

537.312.62 2032

Effect of Plastic Deformation and Annealing Temperature on Superconducting Properties—J. J. Hauser and E. Buehler. (*Phys. Rev.*, vol. 125, pp. 142–148; January, 1962.)

537.312.62 2033

Superconducting Penetration Depth Measurements in Aluminium at 175 Mc/s—W. L. McLean. (*Proc. Phys. Soc.* (*London*), *A*, vol. 79, pp. 572–585; March, 1962.)

537.312.62 2034

The Surface Impedance of Superconducting Aluminum at 3 Gc/s—D. L. Williams. (*Proc. Phys. Soc.* (*London*), *A*, vol. 79, pp. 594–598; March, 1962.)

537.312.62 2035

Superconducting Titanium-Molybdenum Alloys—R. D. Blaugher, B. S. Chandrasekhar, J. K. Hulm, E. Corenzwit, and B. T. Matthias. (*J. Phys. Chem. Solids*, vol. 21, pp. 252–255; December, 1961.)

537.58 2036

Electronic and Absorption Properties of Barium Films on Tungsten—Ya. P. Zingerman, V. A. Ishchuk, and V. A. Morozovskiĭ. (*Fiz. Tverdogo Tela*, vol. 2, pp. 2276–2286; September, 1960.)

538.22 2037

Antiferromagnetic-Ferromagnetic Transformation in FeRh—L. Muldawer and F. de-Bergevin. (*J. Chem. Phys.*, vol. 35, pp. 1904–1905; November, 1961.) An experimental study of FeRh shows that the theory of Kittel (970 of 1961) can be applied to the system.

538.221 2038

The Magnetic Characteristics of Fe-Al Single Crystals—H. Gengnagel. (*Z. angew. Phys.*, vol. 13, pp. 527–534 and 569–576; November and December, 1961.)

Part 1—The Influence of the Degree of Ordering on Magnetic Properties (pp. 527–534).

Part 2—The Influence of Precipitates on Coercivity and Remanence of Fe-Al Lattice Single Crystals (pp. 569–576).

538.221:538.569.4 2039

Susceptibility of Ferromagnets in a Strong R.F. Magnetic Field Applied Parallel to the D.C. Field—J. J. Green and E. Schlömann. (*J. Appl. Phys.*, vol. 33, pp. 535–537; February, 1962.) The high-power susceptibility has been measured as a function of the dc field at three frequencies on Y-Fe garnet with and without substitutions of Ho and Ga.

538.221:538.569.4 2040

Longitudinal Susceptibility of Ferromagnets in Strong R.F. Fields—E. Schlömann (*J. Appl. Phys.*, vol. 33, pp. 527–534; February, 1962.) The mechanism of spin-wave instability in an RF field applied parallel to the dc field is explained, and theoretical and experimental results are compared.

538.221:538.569.4 2041

Magnetic-Field Dependence of the Enhancement Factor for Nuclear Resonance in Ferromagnets—M. W. Muller and A. Sher. (*Phys. Rev. Lett.*, vol. 8, pp. 85–86; February, 1962.) Measurements of the enhancement factor in nuclear resonance can provide information about the internal structure of Bloch walls. An experiment with hexagonal $BaFe_{12}O_{19}$ is suggested.

538.221:538.569.4 2042

Paramagnetic Resonance Width in Iron and Nickel—B. R. Cooper and F. Keffer. (*Phys. Rev.*, vol. 125, pp. 896–900; February, 1962.) The large line widths of microwave absorption of single crystals above the Curie point is ascribed to a pseudo-dipolar component in the perturbing spin coupling.

538.221:538.65 2043

Magnetomechanical Chladni Figures: an Anisotropy of the ΔE Effect—H. C. Siegmann. (*Z. Phys.*, vol. 165, pp. 369–386; November, 1961.) Investigations of changes of the modules of elasticity E due to magnetization and as a function of the direction of application of stresses.

538.221:539.23 2044

Saturation Magnetization and Anisotropy Field Strength in Thin Vapour-Deposited Iron Films—H. Hoffmann. (*Z. Phys.*, vol. 165, pp. 261–287; November, 1961.) A method of vapor deposition is described which ensures the structural uniformity of the films produced and, hence, the reproducibility of the coercivity characteristics as a function of film thickness. See also 4219 of 1961.

538.221:539.23 2045

Magnetic Domains in Coarse-Crystal Nickel-Iron Films—E. Fuchs and A. Politycki. (*Z. angew. Phys.*, vol. 13, pp. 541–544; November, 1961.) Electron-microscope investigations on electrolytically produced permalloy films. See also 1635 of May (Politycki).

538.221:539.23:538.614 2046

The Display of Magnetic Fine Structures by means of the Faraday Effect—H. Boersch and M. Lambeck. (*Z. Phys.*, vol. 165, pp. 176–183; November, 1961.) Report on the further development of a method described earlier (2312 of 1961) with illustrations of magnetization patterns.

538.221:621.317.4:621.385.833 2047

The Application of an Electron-Optical Method for Magnetic Measurements on Ferromagnetic Cylinders—H. Murrmann. (*Z. Phys.*, vol. 165, pp. 305–321; November, 1961.) See also 3875 of 1961 (Schwink) and 259 of January (Murrmann and Schwink).

538.221:621.318.134 2048

Ferrite Materials for High Temperatures—Y. Lescroel. (*Onde élect.*, vol. 42, pp. 124–130; February, 1962.) The composition and properties of ferrites developed to function at 250°C are described and details of some applications are given.

538.221:621.318.134 2049

The Influence of the Addition of Cobalt on the Frequency Dependence of the Complex Permeability of Ni-Zn Ferrite—F. Voigt. (*Z. angew. Phys.*, vol. 13, pp. 538–541; November, 1961.) Measurements were made on specimens with and without CoO content, in the frequency range 2–300 Mc. See also 4233 of 1961.

538.221:621.318.134 2050

Magnetic Properties of Cobalt Titanate—N. Sakamoto. (*J. Phys. Soc. Japan*, vol. 17, pp. 99–102; January, 1962.) A report of measurements at temperatures down to 4.2°K.

538.221:621.318.134 2051

Mechanism of Disaccommodation in Ferrites—S. Iida. (*J. Phys. Soc. Japan*, vol. 17, pp. 123–127; January, 1962.) By controlling the density of cation vacancies disaccommodation $\Delta\mu_0/\mu_0$ in Mn-Zn ferrites can be reduced to less than 0.02 per cent.

538.221:621.318.134 2052

Substitution of Fe^{3+} Ion in Sc_2O_3 and In_2O_3—S. Geller, H. J. Williams and R. C. Sherwood. (*J. Chem. Phys.*, vol. 35, pp. 1908–1909; November, 1961.) An examination of some of the magnetic properties of crystals of Sc_2O_3 and In_2O_3 after considerable amounts of Fe^{3+} have replaced Sc^{3+}.

538.221:621.318.134 2053

Some Properties of Complex Rare-Earth Garnets—G. Villers and J. Loriers. (*J. phys. radium*, vol. 22, pp. 773–774; November, 1961.) A continuation of previous work (*e.g.*, 2331 of 1959) on more complex garnets.

538.221:621.318.134:537.311.33 2054

Electrical Conduction in Nickel Ferrous Ferrites—T. Kohane and B. D. Silverman. (*J. Phys. Soc. Japan*, vol. 17, pp. 249–250; January, 1962.) A possible explanation is given and its validity checked by measurement. See also 2721 of 1961 (Miyata).

538.221:621.318.134:538.569.4 2055

Propagation Effects on Ferromagnetic Resonance in Dielectric Slabs—P. Pincus. (*J. Appl. Phys.*, vol. 33, pp. 553–556; February, 1962.) The effects of displacement currents on ferromagnetic resonance are investigated for perfectly insulating slabs magnetized normal to their surface. Shifts in the resonance are found.

538.222:538.569.4 2056

On the Exactness of the Spin-Hamiltonian Description of Fe^{3+} in Sapphire—H. F. Symmons and G. S. Bogle. (*Proc. Phys. Soc. (London)*, *A*, vol. 79, pp. 468–472; March, 1962.)

538.63:539.23 2057

The Measurement of the Magnetoresistance Effect on Rectangular Plates—P. Cotti. (*Helv. Phys. Acta*, vol. 34, pp. 777–779; December, 1961. In German.) Results of measurements on In films are discussed with reference to the formulas given by Lippmann and Kuhrt (932 of 1960).

539.2:537.311.33:061.3 2058

International Conference on Chemical Physics of Nonmetallic Crystals—(*J. Appl. Phys.*, vol. 33, suppl., pp. 251–518; January, 1962.) 45 papers presented at the conference held at Northwestern University, Evanston, Ill., August 28–31, 1961.

548.5 2059

Problems associated with Distribution Coefficient and Solid Solubility Determinations using Crystal Growth Techniques—W. Bardsley, D. T. J. Hurle, and J. B. Mullin. (*J. Electrochem. Soc.*, vol. 109, pp. 64–65; January, 1962.) Some conditions are given under which the solid-liquid interface can become faceted and which can occur for any growth orientation in the solvent evaporation technique described by Trumborse, *et al.* (196 of January).

666.3:621.385.032.7 2060

'Vitrokeram' Cement—a New Material for Vacuum Techniques—I. Bornemann. (*Nachrtech.*, vol. 11, pp. 488–492; November, 1961.) Physical and chemical properties of "pyroceram" materials are summarized, and their application in the manufacture of vacuum tubes, in particular color-television tubes, is described.

MATHEMATICS

518.4 2061

On Trees of a Graph and their Generation—S. L. Hakimi. (*J. Franklin Inst.*, vol. 272, pp. 347–359; November, 1961.) Those properties of a set of trees which can be used to generate the trees of a given graph are presented. Two different methods are described.

MEASUREMENTS AND TEST GEAR

621.3.018.41(083.74):621.373.421.13.029.6 2062

A Crystal Harmonic Microwave Reference—C. M. Cade and A. T. Elliott. (*Brit. Commun. Electronics*, vol. 9, pp. 202–205; March, 1962.) A reliable and inexpensive frequency standard for *X*-band measurements is described. Harmonics are spaced at 270-Mc intervals and accuracy is within 1 part in 10^7.

621.317.311:621.376.32 2063

A Semiconductor Current Amplifier—N. L. Gregory and J. E. Lewin. (*Electronic Eng.*, vol. 34, pp. 155–157; March, 1962.) A voltage-sensitive diode, RF modulator and frequency discriminator are combined and over-all current feedback is used to stabilize the gain. Current measurements in the range $10^{-6}-10^{-12}$ a are possible.

621.317.341:621.372.8 2064

The Attenuation Measurement of Low-Loss Specimens in a Waveguide—J. H. Heath and E. T. Clothier. (*Electronic Eng.*, vol. 34, pp. 148–154; March, 1962.) An extension of work by Cullen (3196 of 1949) in which the standard wave pattern is shifted relative to a fixed probe by a movable short circuit. A rigorous analysis of the method is given.

621.317.353.1 2065

A New Method for Measuring Amplitude-to-Phase-Modulation Conversion and Amplitude-Modulation Compression—T. Sárkány. (Proc. IRE, pt. B, vol. 109, pp. 151–155; March, 1962.) The technique is based on compensating the unknown PM of the output signal with the known input PM, the exact equality being indicated by noting the coincidence and minimum value of the two sidebands.

621.317.7:621.382.23:621.372.44 2066

Measuring Capacitance of Varactor Diodes Dynamically—W. Jasinski. (*Electronics*, vol. 35, pp. 60–61; March, 1962.) A test arrangement of two CRO is described for displaying variations in capacitance and conduction characteristics as functions of the sweep voltage.

621.317.727.1 2067

A Seven-Decade Adjustable-Ratio Inductively Coupled Divider with 0.1 Part per Million Accuracy—J. J. Hill and A. P. Miller. (Proc. IRE, pt. B, vol. 109, pp. 157–162; March, 1962.) Discusses errors arising when several dividers are connected together.

OTHER APPLICATIONS OF RADIO AND ELECTRONICS

531.78:537.311.33:537.228.1 2068

Pressure Transducers—W. P. Mason. (*Electronics*, vol. 35, pp. 35–39; February, 1962.) The use of semiconductor devices as strain gauges is described. A transducer which exhibits piezoelectric properties at more than 1 Gc may find application in delay lines and in light-modulation devices.

535.2-15 2069

Signal Generator for Infrared Region—A. Glaser. (*Electronics*, vol. 35, pp. 40–43; February, 1962.) The desired wavelength in the range 1–14 μ is selected by an optical filter from the radiation of a tungsten filament lamp. Internal amplitude modulation from 2 cps to 2.6 kcs, step and vernier attenuation and an output power monitor are provided.

621.362:537.319.62 2070

Thermodynamics of a Superconducting Energy Converter—M. Chester. (*J. Appl. Phys.*, vol. 33, pp. 643–647; February, 1962.) A thermodynamic analysis is given for a cyclic energy conversion process based on the phase transition in a superconductor. Efficiencies as high as 44 per cent may be obtainable under ideal conditions.

621.362:621.387 2071

A Note on the Theoretical Efficiency for Energy Transformation using Thermionic Emission—J. Myatt and L. G. Sanders. (*J. Electronics and Control*, vol. 11, pp. 95–99; August, 1961.) A theoretical analysis which shows that when diodes are used as energy transducers a low cathode work function is not compatible with low efficiency.

621.362:621.387 2072

Some Considerations of Dynamic Behaviour in the Plasma Thermocouple—R. W. Bussard. (*J. Appl. Phys.*, vol. 33, pp. 606–613; February, 1962.) An analysis is presented of the role which stable electron oscillations of large amplitude may play in determining observed steady-state characteristics of a plasma-filled thermionic diode.

621.362:621.387 2073

Investigations on Direct Energy Conversion by means of the Cs Diode.—K. G. Günther. (*Z. angew. Phys.*, 1961. vol. 13, pp. 501–508; November, 1961.) The effect of various cathode and anode materials on the operation of a Cs plasma cell [see, *e.g.*, 1280 of 1961 (Ranken, *et al.*)] and the influence of other parameters are examined.

621.384.612.22 2074

The Electron Synchrotron of Frascati—M. Puglisi and G. Sacerdoti. (*Alta Frequenza*, vol. 30, pp. 755–766; November, 1961.) Detailed description of the equipment and operation of a 1-Gev machine.

621.385.833 2075

Electron Wave Inteference: Application to a Method of Interference Electron Microscopy.—J. Faget. (*Rev. d'Optique*, vol. 40, pp. 347–381; July, 1961.) The theory and design of equipment for interferometry using a magnetic electron lens are discussed. Applications of the apparatus for measuring the phase displacement and internal potential of a specimen are described. 69 references.

621.385.833 2076

Intensification of the Electron-Microscope Image using Cathode-conductivity in Selenium—M. E. Haine and P. A. Einstein. (Proc. IRE, pt. B, vol. 109, pp. 185–195; March, 1962.) Operation of an electron microscope under conditions of optimum resolving power is difficult. A method of overcoming this by using a dynamic image intensifier is proposed.

PROPAGATION OF WAVES

621.391.812.623 2077

Influence of the Earth in Transhorizon Propagation—F. du Castel. (*Onde élect.*, vol.

42, pp. 48–66; January, 1962.) The complex-integral method of Fock is applied to ultra-short-wave diffraction phenomena caused by the earth and its surface features.

621.391.812.63.029.45 2078

An Extension to V.L.F. Reflection Coefficients—E. C. Field, P. Tamarkin, and E. M. Fairbrother. (*J. Geophys. Res.*, vol. 67, pp. 898–901; February, 1962.) Formulas and numercial results derived earlier [278 of January (Field and Tamarkin)] are extended to propagation in an arbitrary direction to the geomagnetic field.

621.391.812.63.029.45:523.75 2079

Prediction of V.L.F. Diurnal Phase Changes and Solar Flare Effect—J. R. Wait: W. D. Westfall. (*J. Geophys. Res.*, vol. 67, pp. 916–918; February, 1962.) Comment on 279 of January, and author's reply.

621.391.812.8:551.510.535 2080

A New Method of Ionospheric Forecasting—R. Naismith, H. C. Bevan, and P. A. Smith. (Proc. IRE, pt. B, vol. 109, pp. 125–130; March, 1962.) Formerly, f_{F2} was predicted from solar and ionospheric indices, with a 30 per cent error.

The new method depends on the recurrence of similar ionospheric conditions in the same month of different years, and has given a 7.3 per cent error. Records of corresponding epochs will eliminate the need to make new forecast charts each month.

RECEPTION

621.391.812.3.029.6 2081

Investigation of Fading in the U.H.F. Range—J. Grosskopf. (*Nachrtech. Z.*, vol. 14, pp. 590–604; December, 1961.) Report on correlation measurements at the receiving end of scatter links operating at 100, 200, 516 and 1850 Mc. The results are analyzed to obtain information on the structure and dynamics of the scattering medium.

621.396.666:621.397.743 2082

Tests of Frequency Diversity Reception over the Path Milan–Mt. Beigua with Three Different Values of Frequency Spacing—P. Quarta. (*Alta Frequenza*, vol. 30, pp. 854–861; December, 1961.) Report on tests at 2 Gc over a 126-km path which is part of the Milan-Palermo television link system [(see, *e.g.*, 3295 of 1960 (Castelli)] with frequency spacings of 80, 120 and 200 Mc.

STATIONS AND COMMUNICATION SYSTEMS

621.391 2083

The Interrelation between 'Reactive,' 'Active' and 'Apparent' Information and the Symbol and Channel Capacity in Information Theory—P. Neikhardt. (*Nachrtech.*, vol. 11, pp. 481–484; November, 1961.) Definition of terms and discussion of their relations to other concepts of information theory.

621.391:621.376.5 2084

Transmission of Multilevel Digital Signals through Noise-Free Distorting Channels—L. W. Hill. (Proc. IRE, pt. B, vol. 109, pp. 165–173; March, 1962.) An examination of the dependence of the rate of transmission of digital information on the number of levels chosen.

621.396+621.397].029.62/.63:061.3 2085

The European V.H.F./U.H.F. Broadcasting Conference, Stockholm 1961—B. Nielsen and I. L. Nielsen. (*Teleteknik, Copenhagen*, vol. 12, pp. 175–199; December, 1961.) A report on the proceedings with details of Danish frequency allocations and coverage plans.

621.396.4:621.391.812.624 2086

Digital Trophospheric Scatter—J. R. Poppe and A. J. Vadasz. (*Commun. and Electronics*, pp. 669–674; January, 1962.) Increased range is obtained with a tropospheric scatter system by using a digital system, although the analog capabilities are sacrified the system gives a range of 150 miles, with a 250-w transmitter, for a 60-wpm teleprinter circuit.

621.396.43:551.507.362.2 2087

The Potentialities of Communication Satellites—W. J. Bray. (*J. IEE*, vol. 8, pp. 77–81; February, 1962.) A discussion of the technical and international problems of developing world-wide communication links in the 1–10 Gc band.

621.396.65:621.396.41 2088

Technical and Economic Effect of Radio-Link Systems in Telecommunications—H. Liebernickel. (*Tech. Mitt. BRF, Berlin*, vol. 5, pp. 123–128; September, 1961.) Comparison of installation costs of various radio-link systems, and discussion of the economics underlying the design and operation of such systems.

621.396.97:621.376.32 2089

Common-Channel Broadcasting with Frequency Modulation—A. Essmann. (*Nachrtech. Z.*, vol. 14, pp. 609–615; December, 1961.) The operation of common-channel FM systems is examined, particularly with regard to interference effects. The usefulness and practical application of such systems are discussed.

621.396.97–182.3 2090

A New Medium-Size Vehicle for Outside Sound Broadcasts—H. Stumvoll. (*Rundfunktech. Mitt.*, vol. 5, pp. 297–304; December, 1961.) The equipment incorporated in the vehicle described includes facilities for stereophonic broadcasts.

SUBSIDIARY APPARATUS

621.311.6 2091

On the Design of Small Economical Radio Frequency E.H.T. Supplies—J. K. Moore. (*J. Brit. IRE*, vol. 23, pp. 195–203; March, 1962.) Particular attention is given to the design of the high-voltage transformer. The type of stabilized eht generator described is suitable for operation at frequencies greater than 40 kc.

621.311.6:551.507.362.2 2092

Satellite Power Supply has Variable Pulse Width—E. Josephson. (*Electronics*, vol. 35, pp. 47–49; February, 1962.) A detailed circuit description of a short-circuit-proof dc-to-dc converter of high efficiency. With an input voltage of 20–34 v, the output voltage is held at 15 v ±1 per cent at a power output of 5–25 w.

621.311.69:621.383.5 2093

Solar Batteries for the Use as the Power Source of Unattended U.H.F. Repeaters—M. Kobayashi, Y. Ishikawa, and K. Hayashi. (*NEC Res. Dev.*, pp. 20–25; October, 1960.) The transmitter-receiver equipment, which has an average consumption of 4.5 w, is supplied by NiCd cells charged from solar batteries with a peak output of 70 w.

TELEVISION AND PHOTOTELEGRAPHY

621.397.13:612.84 2094

An Assessment of Various Influences on the Gradation of Television Pictures—H. Grosskopf. (*Rundfunktech. Mitt.*, vol. 5, pp. 287–294; December, 1961.) Picture quality as affected by the over-all transfer characteristics of the system and by room illumination is discussed. See also 1710 of May.

621.397.132:621.397.62 2095

An Experimental Fluorescent Screen in Direct-Viewing Tubes for Colour Television—R. R. Bathelt and G. A. W. Vermeulen. (*Philips Tech. Rev.*, vol. 23, pp. 133–141; February, 1962.) A technique is described for the production of a shadow-mask screen in which sulphides are used for all the phosphors. It has 40–50 per cent higher luminance and much less persistence than a conventional screen with red-fluorescent phosphate and green-fluorescent silicate.

621.397.232.6 2096

Improvement of the Transmission Quality of the Television Vestigial-Sideband System by the Introduction of Quadrature Equalization—H. Hopf and S. Dinsel. (*Rundfunktech. Mitt.*, vol. 5, pp. 272–280; December, 1961.) The distortion effect of the quadrature component is analyzed. A method of quadrature equilization at the transmitter is proposed, and the resulting improvement in picture quality is illustrated.

621.397.331.222:621.397.61:621.317.7 2097

Measurement Apparatus Equipment for the Investigation of Inertia Effects in Endikons—W. Abraham. (*Nachrtech.*, vol. 11, pp. 504–507; November, 1961.) The construction and operation of a vidicon-type camera tube are outlined. The equipment described is used to determine the inertia of the photosensitive films.

621.397.331.24.032.36 2098

Problems of Screen Manufacture for Television Picture Tubes—I. Hangos. (*Nachrtech.*, vol. 11, pp. 492–495; November, 1961.) Review of manufacturing techniques with particular regard to optical and chemical properties of screens and the difficulties of overcoming imperfections. 36 references.

621.397.334:621.397.621:621.317.7 2099

Electronic Equipment for a Colour-Picture Tube Test Bench—G. Emmrich. (*Nachrtech.*, vol. 11, pp. 499–504; November, 1961.) The equipment described is designed for the testing of raster homogeneity and color alignment in mask-type picture tubes.

621.397.61 2100

Progress in the Construction of German Television Studio Equipment—F. Rudert. (*Rundfunktech. Mitt.*, vol. 5, pp. 264–271; December, 1961.) Review with details of design standardization achieved for fixed control and camera equipment.

621.397.61:629.19 2101

Ranger Vidicon TV Camera uses Electrostatic Deflection—J. F. Mason. (*Electronics*, vol. 35, pp. 26–27; February, 1962.) Details of construction and operation of the television system used in the Ranger space vehicle.

621.396.63:621.395.625.3 2102

Equipment for the Detection of Drop-Outs on Video Magnetic Tapes—D. Waechter. (*Rundfunktech. Mitt.*, vol. 5, pp. 295–296; December, 1961.) Signal breaks on the tape are counted and the result is displayed on a recording chart.

621.397.7–182.3 2103

Eurovision Outside-Broadcast Vehicle of Westdeutscher Rundfunk—G. Kastern. (*Rundfunktech. Mitt.*, vol. 5, pp. 281–286; December, 1961.) The vehicle described contains all the sound equipment required for a Eurovision transmission of television outside broadcasts.

621.397.712.3 2104

The A. Lelluck Television Centre in Paris—A. Parrot and M. Morel. (*E.B.U.*, vol. 70A, pp. 230–240; December, 1961.) Description of the functions, layout and installations of the RTF television center.

621.397.74(41-4) 2105

U. K. Television—(*Wireless World*, vol. 68, pp. 210–211; May, 1962.) Tables of existing BBC and ITA stations arranged in channel order, and maps showing their coverage are given.

TUBES AND THERMIONICS

621.382 2106

Using Instability Characteristics of Semiconductor Plasmas—M. Glicksman. (*Electronics*, vol. 35, pp. 56–59; March, 1962.) A review of the oscillistor and other new components which are being developed from results of investigations of plasma behavior in solid-state materials.

621.382 2107

Noise Smoothing Factors in Insulator Diodes—N. J. Anderson and B. Meltzer. (*J. Electronics and Control*, vol. 11, pp. 111–113; August, 1961.) Measurements were made at a frequency of 20 Mc of fluctuations in space-charge-limited currents in CdS diodes. Values of smoothing factor as low as 0.17 were obtained.

621.382.2:538.63 2108

A Proposed New Bismuth Device utilizing the Electron-Photon Interaction—L. Esaki. (PROC. IRE, vol. 50, pp. 322–323; March, 1962.) The nonlinearity in the I/V curve of Bi crystals at low temperatures due to a sharp drop in the transverse magnetoresistance noted earlier (1596 of May) permits the building-up of acoustic oscillations depending on crystal dimensions. The two-terminal solid-state device proposed may be used as RF detector or mixer, or for switching applications with very fast response time, the frequency limit being set by the scattering time of about 5×10^{-10} sec.

621.382.23:538.63 2109

Indium Antimonide Tunnel Diodes in High Magnetic Fields—P. N. Butcher, J. A. Hulbert, and K. F. Hulme. (*J. Phys. Chem. Solids*, vol. 21, pp. 320–324; December, 1961.) The results of measurements on diodes with different donor concentrations are interpreted on the basis of a theory of tunneling through a parabolic potential barrier.

621.382.23:621.372.44 2110

The Nonlinear Characteristics of Semiconductor Dipoles—J. Neirynck. (*Rev. HF, Brussels*, vol. 5, pp. 103–108; 1962.) A review of observed effects in *p-n*-junction devices with nonlinear resistive and reactive characteristics, and the equivalent circuits which have been proposed to explain them.

621.382.23:621.372.44:621.317.7 2111

Measuring Capacitance of Varactor Diodes Dynamically—Jasinski. (See 2066.)

621.382.23:621.374.3 2112

Tunnel Devices as Switching Elements—I. Aleksander and R. W. A. Scarr. (*J. Brit. IRE*, vol. 23, pp. 177–192; March, 1962.) Methods of describing the gain of a tunnel diode are suggested and an approximate method of determining its switching time is explained. Applications discussed include a multiplier and binary counter.

621.382.3:621.362 2113

The Thermoelectric Transistor: a Possible Batteryless Amplifying Semiconductor Device—A. Kelen and P. Svedberg. (*Appl. Sci. Res.*, vol. B, no. 5, pp. 369–378; 1957.) A signal, modulating by carrier emission the concentration of free carriers in a semiconductor wafer containing a temperature gradient, is reproduced by the thermoelectric voltage between output electrodes at different temperatures. The conditions for power amplification are discussed. Criteria are derived for the choice of material, geometrical shape and heat flow through an amplifying device. The use of Ge seems to be possible, though difficult. New semiconducting materials show promising properties.

621.382.333 2114

Depletion-Layer Properties in Double-Diffused Transistors—D. P. Kennedy and R. R. O'Brien. (*J. Electronics and Control*, vol. 11, pp. 303–315; October, 1961.) Depletion-layer widths are calculated for the equilibrium emitter junction and for the reverse-biased collector junction. Applications of the analysis are presented for a wide range of physical and geometrical parameters.

621.382.333:539.12.04 2115

Investigation of Recombination Processes in Neutron-Irradiated Ge *p-n-p* Transistors—H. Bilger. (*Helv. Phys. Acta*, vol. 34, pp. 909–928; December, 1961. In German.) Good agreement was obtained in applying the Hall-Shockley-Read model to describe the influence of irradiation-generated recombination centers on several transistor parameters, but large differences in the values of lifetime were found.

621.383.5 2116

Photocapacitance and Inductance in GaP Point-Contact Diodes—A. Epstein and J. Caldwell. (PROC. IRE, vol. 50, p. 331; March, 1962.) Results are given of capacitance and resistance measurements as a function of frequency, both with and without light, and at various voltage levels.

621.383.52 2117

Germanium Photodiodes with Small Inertia—S. M. Ryvkin, R. F. Konopleva, L. V. Maslova, O. A. Matveev, N. B. Strokan, D. V. Tarkhin, and G. V. Khozov. (*Fiz. Tverdogo Tela*, vol. 2, pp. 2199–2201; September, 1960.) A report of measurements on low-inertia photodiodes with sensitive surface area 0.2 and 1 mm² and dark current 0.2–1.00 and 5–10 μa, respectively. Sensitivity is several hundred times that of former types.

621.385.032.213 2118

Temperature Dependence of the Work Function of Semiconductor Thermionic Cathodes—B. V. Bondarenko. (*Fiz. Tverdogo Tela*, vol. 2, pp. 2140–2151; September, 1960.) A detailed report of measurements on cathodes of Sc_2O_3, Y_2O_3, La_2O_3, TiO_2, ZrO_2, HfO_2 and tungstates of Ba, Sr and Ca at temperatures up to 2000°K.

621.385.032.213.23:621.391.822.33 2119

Investigation of the Causes of Flicker Noise in Oxide Cathodes—H. Pinsler. (*Arch. elekt. Übertragung*, vol. 15, pp. 515–517; November, 1961.) Two principal theories of the origin of flicker noise are discussed. Experimental results indicate that this noise must be attributed to other mechanisms in addition to fluctuations of the work function.

621.385.032.213.6 2120

A Note on Anomalous Radial Velocity Spectra from Rough Thermionic Emitters—H. Moss. (*J. Electronics and Control*, vol. 11, pp. 289–295; October, 1961.) Rough cathodes can yield high apparent radial velocities (10–20 ev) for electrons under temperature-limited conditions, which disappear when the cathodes are smoothed or operated under space-charge-limited conditions. A simple theory explains the findings.

621.385.23 2121

Calculation of the Dependence of the Anode Current of a Plane-Parallel Diode on the Cathode Work Function—H. Pinsler. (*Arch. elekt. Übertragung*, vol. 15, pp. 518–520; November, 1961.) See also 2119 above.

621.385.6 2122

D.C. and A.C. Energy Flow in High-Velocity Electron Beams—W. Riedler. (*Arch. elekt. Übertragung*, vol. 15, pp. 521–524; November, 1961.) The splitting of energy flow according to the electrokinetic power theorem is considered in the case of three-dimensional beams at relativistic velocities. See 1099 of March.

621.385.6:621.375.9:621.372.44 2123

Cyclotron-Wave Interaction in Spatially Periodic Electrostatic Quadrupole Fields—J. C. Bass and M. G. F. Wilson. (*J. Electronics and Control*, vol. 11, pp. 125–144; August, 1961.) The small-signal theory of transverse interaction of cyclotron waves on filamentary electron beams with spatially periodic fields is discussed with particular reference to the electrostatic quadrupole amplifier. Gain expressions, including the case of nonoptimum pumping, are derived.

621.385.6:621.375.9:621.372.44 2124

The efficiency of Electrostatic Quadrupole Amplifiers—H. J. Curnow. (*J. Electronics and Control*, vol. 11, pp. 161–176; September, 1961.) The operation is examined taking into account the variations of axial velocity, the contribution to the total energy by the electrostatic pump, and the true form of the twisted quadrupole field. The efficiency is unlikely to exceed 25 per cent.

621.385.63 2125

Ultra-Low-Noise Travelling-Wave Tube with Simple Electron-Gun Structure—B. G. Bosch and K. B. Niclas. (PROC. IRE, vol. 50, pp. 324–325; March, 1962.) Ultra-low noise figures in traveling-wave tubes hitherto attained by complex techniques can be obtained by conventional low-noise guns when the cathode coating has a sharply defined edge.

621.385.632.3 2126

Multiple-Stream Crossed-Field Interaction—O. P. Gandhi. (*J. Electronics and Control*, vol. 11, pp. 81–94; August, 1961.) Dispersion equations are developed for the crossed-field double-beam forward-wave amplifier and the double-beam drift-space amplifier. It is easier to achieve high gain with the double-beam device because of the simplicity of obtaining Brillouin flow.

621.385.644.2 2127

Symmetrical Tuning of a Multiresonator Magnetron—T. S. Chen. (*J. Electronics and Control*, vol. 11, pp. 241–279; October, 1961.) Results show that it should be possible to operate a tunable magnetron over the frequency range 9.5–10.7 Gc. The merits of a particular structure are enumerated.

621.385.832.032.265 2128

Manufacturing Moulded Electron Guns—E. C. Gear. (*Electronics*, vol. 35, pp. 74, 76; February, 1962.) Prototype design and production problems are outlined.

621.387:621.362 2129

A Note on the Theoretical Efficiency for Energy Transformation using Thermionic Emission—Myatt and Sanders. (See 2071.)

621.387:621.362 2130

Some Considerations of Dynamic Behaviour in the Plasma Thermocouple—Bussard. (See 2072.)

621.387:621.362 2131

Investigations on Direct Energy Conversion

by means of the Cs Diode—K. G. Günther. (See 2073.)

621.387(083.72) 2132

Gas Discharge Tubes in Telecommunications: Terminology—(*Nachrtech. Z.*, vol. 14, pp. 616–622; December, 1961.) A list of sixty-six terms and their definitions recommended by the Nachrichtentechnische Gesellschaft, with corresponding English and French terms.

621.387.132.2 2133

Inert-Gas Clean-Up in the Hot-Cathode Discharge—R. F. Hall. (*J. Electronics and Control*, vol. 11, pp. 101–109; August, 1961.) The results of an experimental investigation are presented which show that the rate of inert-gas clean-up depends on the rate of increase of sputtered deposits on surfaces adjacent to the discharge. The rate of electrode sputtering is dependent on the plasma density gradient in its vicinity.

621.387.322 2134

Characteristics and Applications of Glow-Discharge Tubes—F. A. Benson. (*Electronis Engrg.*, vol. 33, pp. 354–359 and 446–451; June and July, 1961.) 141 references.

MISCELLANEOUS

621.38(083.72) 2135

A Dictionary of 'Trons'—J. H. Jupe. (*Brit. Commun. Electronics*, vol. 9, pp. 194–201; March, 1962.) 577 words ending in "tion" are given. For an earlier glossary see 2107 of 1950 (White).

621.39(047.1) 2136

Communication Engineering and Radiolocation—(*VDI Z.*, vol. 104, pp. 215–232; February, 1962.) Progress report covering recent developments, with references mainly to German literature. The following sections are surveyed:

1) Telecommunications—H. Englbrecht (pp. 215–217).
2) Sound Broadcasting and Television—K. Müller (pp. 217–222). 116 references.
3) Radar and Radio Navigation—W. Stanner (pp. 222–224).
4) Electroacoustics—H. Harz (pp. 224–228). 68 references.
5) High-Frequency Measurements—A. Egger (pp. 229–232). 73 references.

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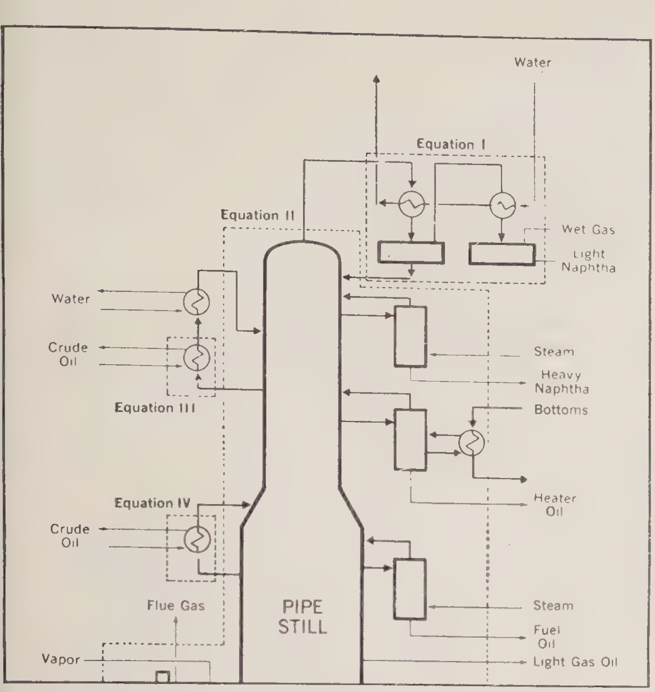

This flow diagram shows a data processing systems engineer's analysis of the major control problems in a petroleum distillation process.

1. Reactor heat balance equation:

$$m_1\dot{y}_1 = \sum_{i=1}^{5} q_i T_i x_i - (\sum_{i=1}^{5} x_i - y_6)\, y_1 h_1 - Q_2(y_1 + a) \sum_{i=1}^{5} x_i + Q_5 - Q_3$$

2. Over-all heat balance equation:

$$\dot{Q} = m_1\dot{y}_1 + m_2\dot{y}_2 = \sum_{i=1}^{6} q_i T_i x_i - [(\sum_{i=1}^{5} x_i - y_6)\, y_1 h_1 + (x_6 + y_7) y_2 h_2]$$

$$+ Q_1\, y_7 - Q_2(y_1 + a) \sum_{i=1}^{5} x_i - (Q_3 + Q_4)$$

3. Over-all coke balance equation:

$$\dot{C} = y_6 - y_7$$

4. Steady state coke burning equation:

$$y_7 = \frac{(b - cy_4)\, x_6}{(cy_4 + 1)\frac{H}{M_H} + \frac{(1 - H)}{M_c}\frac{(2k + cy_4 + 1)}{k + 1}}$$

These equations are the mathematical model for a catalytic cracking process. A similar model would be formulated for controlling the process at left.

As military and business operations grow more complex, they become more difficult to manage. The dynamics of large-scale operations shift so rapidly that management is often unaware of changes until after they have taken place. To keep complex operations performing properly, IBM is developing fully automatic systems and man-machine systems which detect variances from prescribed limits and take action on them before serious problems can arise.

Fully automatic closed-loop systems encounter unusual environmental and diagnostic problems. To prevent bending of large missiles during powered flight, IBM engineers are studying digital filter techniques which suppress bending-mode vibrations sensed in the attitude control loops. To formulate the mathematical model of the world's largest crude-oil distillation unit, it was necessary for IBM scientists to determine the relationships between 20 independent and 60 constrained variables, and the conditions of the process. Using linear programming techniques, they were then able to establish operating limits which would produce optimum process performance.

Criteria for man-machine systems, in which the computer assists human beings in control and decision making, are less easy to define. Operating limits, or set points, are seldom predetermined. For example, the design of a military system depends on knowledge of field operations, such as the information an army commander needs to utilize his forces most efficiently.

In addition, "human elements" add to the empirical nature of man-machine systems. Timely change-of-status reports lose their significance unless human beings can understand them immediately. IBM systems engineers are conducting extensive studies to establish the most effective ways of conveying information from machines to men. They are analyzing the information exchange which makes possible each step in different manufacturing and military operations. Out of their research may come the dynamic, real-time operational control systems of tomorrow.

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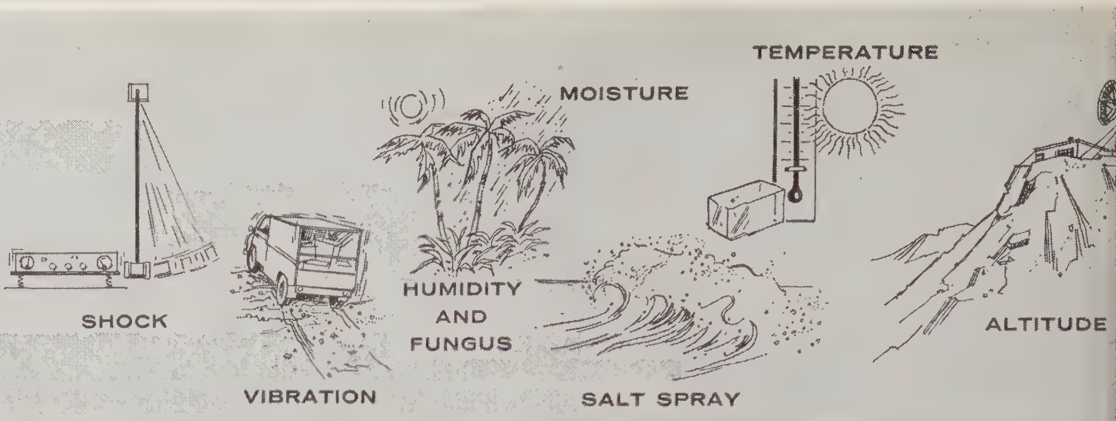
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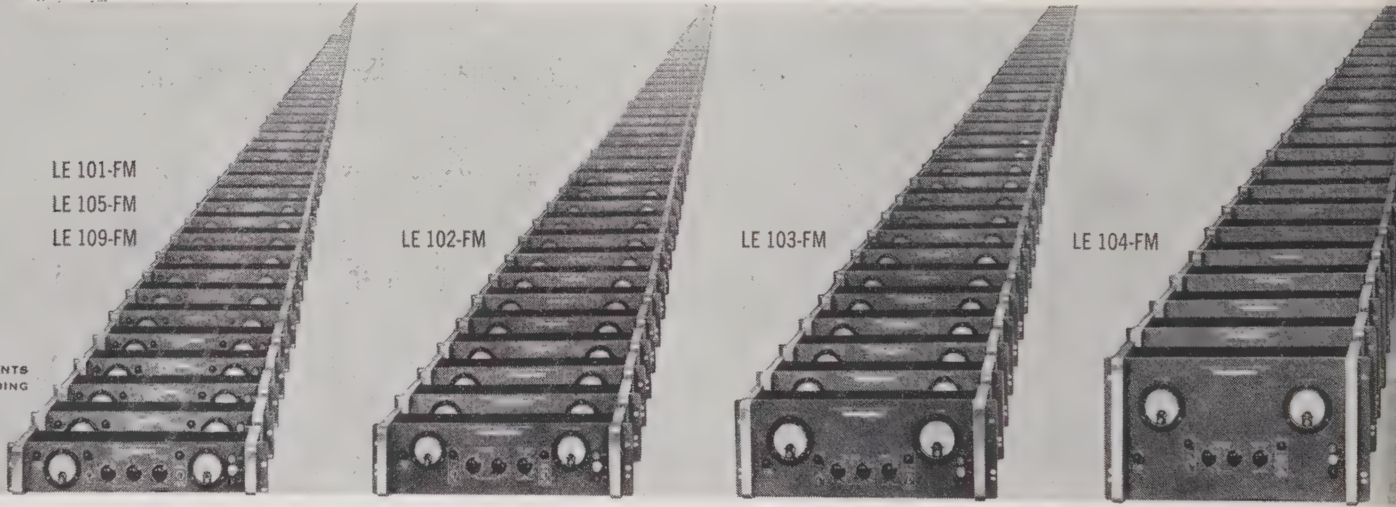
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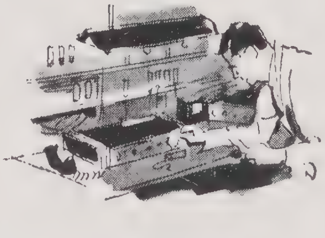

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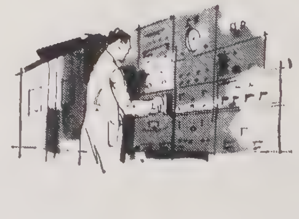

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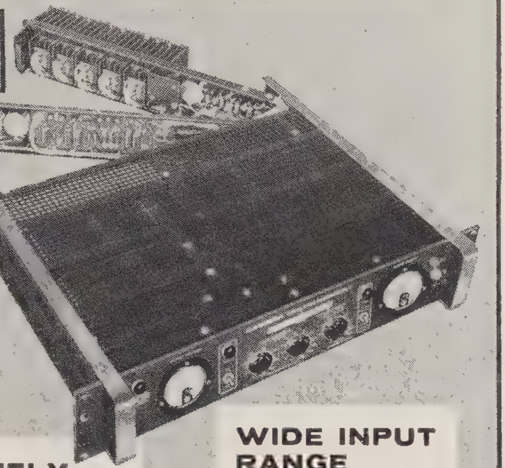

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Model	Voltage Range	Current Range	Price(2)
LE101	0-36 VDC	0- 5 Amp	$420
LE102	0-36 VDC	0-10 Amp	525
LE103	0-36 VDC	0-15 Amp	595
LE104	0-36 VDC	0-25 Amp	775
LE105	0-18 VDC	0- 8 Amp	425
LE109	0- 9 VDC	0-10 Amp	430

(1)Current rating applies over entire voltage range.
(2)Prices are for nonmetered models. For models with ruggedized MIL meters add suffix "M" to model number and add $40 to the nonmetered price. For metered models and front panel control add suffix "FM" and add $50 to the nonmetered price.

REGULATED VOLTAGE:

Regulation (line) ......Less than .05 per cent or 8 millivolts (whichever is greater). For input variations from 105-135 VAC.

Regulation (load) ......Less than .05 per cent or 8 millivolts (whichever is greater). For load variations from 0 to full load.

Transient Response
(line) ....Output voltage is constant within regulation specifications for any 15 volt line voltage change within 105-135 VAC.

(load) ....Output voltage is constant within 25 MV for load change from 0 to full load or full load to 0 within 50 microseconds of application.

Remote Programming ...50 ohms/volt constant over entire voltage range.

Ripple and Noise ....Less than 0.5 millivolt rms either positive or negative terminal grounded.

Temperature Coefficient. .Less than 0.015%/°C.

DC OUTPUT (CURRENT REGULATED FOR LINE AND LOAD)(3)

Current range 10% to 100% rated load for entire voltage range. Full specifications upon request.

AC INPUT ....105-135 VAC; 45-66 CPS and 320-480 CPS in two bands selected by switch.

OPERATING AMBIENT TEMPERATURE AND DUTY CYCLE..............Continuous duty at full load 0°C to +50°C (122°F) ambient.

OVERLOAD PROTECTION:

Thermal ....Thermostat, reset by power switch, thermal overload indicator light front panel.

Electrical:
External Overload
Protection ....Adjustable, automatic electronic current limiting circuit limits the output current to the preset value upon external overloads, including direct short, thereby providing protection for load as well as power supply. Current limiting settable from 10% to 110% of load.

METERS:..................Ruggedized voltmeter and ammeter to Mil-M-10304B specifications on metered models.

CONTROLS:

DC Output Controls . . Coarse and fine voltage adjust and current adjust on front panel for models with suffix "FM", all other models same controls are mounted in rear.

PHYSICAL DATA:

Mounting.................... Standard 19" rack mounting.

Size		
Size.......	LE101, LE105, LE109	3½" H x 19" W x 16" D
	LE102,	5¼" H x 19" W x 16" D
	LE103,	7" H x 19" W x 16½"D
	LE104,	10½" H x 19" W x 16½"D

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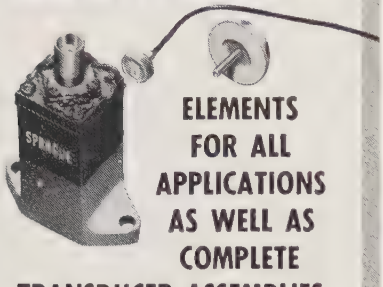

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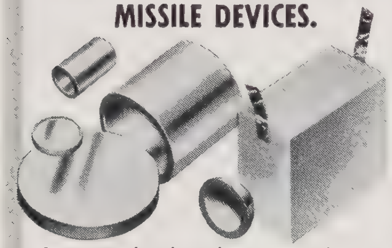

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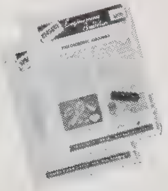

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Section Meetings

(Continued from page 80A)

Florida West Coast

"Space System Reliability," L. S. Gephart, NASA; Joint with ASQC; 4/18/62.

Fort Wayne

"Storage Tubes," R. W. Hunter, ITT Industrial Labs.; 5/10/62.

Fort Worth

"Crossroads for Engineers," P. E. Haggerty, President IRE; 3/22/62.

"Problem Definition and Translation for a Computer," G. D. Pirtle, IBM Corp.; 3/27/62.

"Introduction to Analog Computers," O. J. Sullivan, Electronic Associates Inc.; 4/5/62.

"Collins Communication and Data Systems," T. Prickett, Jr., Collins Radio Co.; 4/10/62.

"Analog Computer Programming," A. I. Katz, Electronic Associates Inc.; 4/12/62.

Gainesville

"A Discussion of An Analog Computer Utilizing the Technique of Memory Time Sharing," O. I. Elgerd, University of Florida; 4/11/62.

"Ferro-Electric Fundamental Properties and Applications," A. L. Stanford, Sperry Microwave Electronics Co.; 5/9/62.

Hawaii

"Survey of Electronic-Scanning Antenna Techniques," P. C. Yuen, Univ. of Hawaii; 2/14/62.

"Bellamy Drift Indicator, Type 60-A," C. Street, Street Lab. of Applied Physics; 3/15/62.

Tour of Diamond Head Crater Facilities of the Federal Aviation Agency, M. O. Schwaegler; 4/11/62.

"Reliability of Redundant Digital System," S. P. Gouveia, Univ. of Hawaii; 5/9/62.

Ithaca

Student Papers Contest; Election of Officers; 5/3/62.

Kansas City

Student Paper Competition; Election of Officers; 5/8/62.

Kitchener-Waterloo

"AN/MPQ-501 Counter Mortar Radar," W. C. Brown, National Research Council; Film and Talk on the Deployment of Mortar Batteries, P. Martel, Army Electrical Equipment Est.; Election of Officers; 4/16/62.

Field Trip to General Instruments Co., E. A. Thomas; 5/14/62.

Las Vegas

Business Meeting; 3/23/62.

Little Rock

"Radioactivity in the Atmosphere," P. Kuroda, Univ. of Arkansas; 1/31/62.

"Communication Systems of the Future," R. Kendricks, Southwestern Bell Telephone; 3/16/62.

"The Rate of Change Factor in Reliability," P. Holden, Texas Instruments, Inc.; 4/19/62.

London-Canada

"A Pre-tour description of the CANDU Nuclear Power Project at Douglas Point, Ontario," A. R. Burge, Canada Limited; 4/23/62.

Lubbock

"Background Music and Commercial FM," J. Blankenship, Background Music Inc.; C. D. Hutton, KBFM; 2/27/62.

"Weather Radar," E. J. Shannon, KDUB-TV; 4/24/62.

"The Navy 2-Megawatt VLF Transmitter," W. D. Mitchell, Continental Electronics; 5/15/62.

New Orleans

Tour and Demonstrations, Standard Television Tube Co., W. T. Freeland; 4/27/62.

New York

"Introduction to Decision Theory," L. S. Schwartz, New York University; 3/26/62.

"Application to Radar Systems—Treatment of the Search Problem," J. J. Bussgang, Signatron Inc.; 4/2/62.

"Application to Signal Detection in Auditory and Visual Areas," D. M. Green, Mass. Institute of Technology; 4/16/62.

"Applications to Communications," W. M. Siebert, Mass. Institute of Technology; 4/23/62.

"Application to Control Systems," S. Horing, Polytechnic Inst. of Brooklyn; 4/30/62.

"Application to Pattern Recognition," W. Highleyman, Bell Telephone Labs.; 5/7/62.

Symposium on "Teaching Machines and Programmed Learning"; 4/14/62.

"Superconducting Solenoids," C. F. Hempstead, Bell Telephone Labs.; Election of Officers; 5/9/62.

North Carolina

Report and discussion of the IRE/AIEE Proposed Merger; Joint with Eastern Subsection; 4/6/62.

Northern New Jersey

Panel Discussion "Space Age Energy Conversion," D. Purdy, General Electric Missile and Space Division; N. Freedman, RCA Tube Division; D. Levine, Esso Research Labs.; K. D. Smith, Bell Telephone Labs.; 4/11/62.

"Advances in Bio-Medical Electronics," L. E. Flory, RCA Labs.; Joint Meeting of NNJS-PGBME; 5/9/62.

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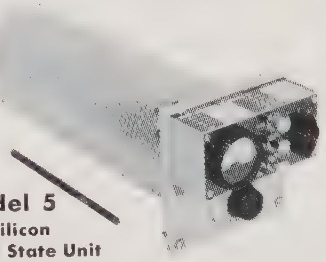

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Northwest Florida

"Highlights of IRE Inter-National Convention," C. D. L. Longaker, Eglin AFB; 4/26/62.

Oklahoma City

Tour of the OSAGE Digital Computer Installation; University of Oklahoma; 4/9/1962.

Omaha-Lincoln

Business Meeting; Report on IRE Convention, W. A. Muir & J. Matejka; 4/6/62.

"Science and Manpower," L. B. Hershey, U. S. Selective Service; "Science and Youthpower In The High Schools," J. Rutledge, Univ. of Neb.; "A Flow Densitometer," R. W. Allington, Instrumentation Specialties; "Heat Energy Conversion to Sound," R. Rose, Univ. of Omaha; "Effects of Neutron Irradiation on Electrical Properties of Transistors," W. Nodean & R. Hiddleston, Univ. of Omaha; "New Multi-Beam Interference Technique for Measuring Thin Films," B. Stern, Univ. of Neb.; "System of FM Multiplex Using Hyde SBIF Concepts," J. A. Brink, Univ. of Neb.; 4/13/62.

Symposium—Engineers In Your Own Back Yard; "The Engineering Profession in the Eyes of the Public," J. O. Grantham, Northern Natural Gas Co.; NES and NSPE Awards; "Diamonds In Your Own Back Yard," M. C. Briggs; Joint Meeting with Nebraska Engineering Society & Nebraska Society of Professional Engineers; 4/26/62.

Ottawa

"Electronic Architecture," J. Deane, RC Navy; "Co-ordinated Ship Electronics Design," S. A. Sherwin, Jr.; Dept. of Navy; Joint with PGMIL Chapter; 4/26/62.

Philadelphia

"Space Physics," Dr. Goett, NASA, Goddard Space Flight Center; 3/7/62.

"Satellite Technology and Systems," S. Sternberg, RCA; 4/9/62.

"Electronics, Medicine, and Human Reproduction," H. Balin, Univ. of Penna., H. S. Dordick, RCA; 5/2/62.

Phoenix

Student Papers; 4/12/62.

"IRE/AIEE Merger," T. Hunter, Vice-President IRE; 5/11/62.

Quebec

"The Electron Microscope," J. Lafontaine, Laval University, Quebec; 2/13/62.

Regina

"Cause and Prevention of Signal Loss in Parabolic Microwave Antennas," J. C. Annett, Andrew Antennae Co.; 2/20/62.

Rochester

"Telecommunications—Rochester's Newest Old Industry," J. H. Voss, General Dynamics/Telecommunication; 12/5/61.

"Optical Maser Research," G. D. Boyd, Bell Telephone Labs.; 12/7/61.

Talk by Very Rev. Charles J. Lavery, St. John Fisher College; 12/12/61.

"Pattern Recognition by Adaptive Networks," L. Kanal, Gen. Dynamics/Electronics; 2/8/62.

"The Proposed Merger of IRE/AIEE," L. Holmes, AIEE; J. Wheeler, IRE; 4/24/62.

"Ultrasonic Surgery," W. J. Fry, University of Illinois; 5/7/62.

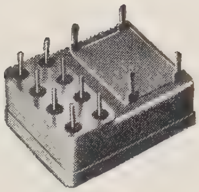
Rome-Utica

"Communication by Orbiting Dipoles," R. M. Lerner, M.I.T. Lincoln Lab.; 4/10/62.

Sacramento

Open Discussion on the Proposed Merger IRE/AIEE; 5/9/62.

(Continued on page 88A)



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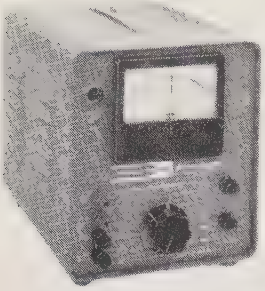

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Section Meetings

(Continued from page 87A)

SHREVEPORT

Student Paper Competition; Joint with AIEE; 3/13/62.

"Electronics Engineers and Their Jobs," Engineers and Educators of the Shreveport Area; 4/3/62.

"Logical Organization of Modern Digital Computers," E. E. Richardson & D. Davis, Control Data Corp.; 5/1/62.

SOUTH CAROLINA

Student Papers Meeting; 5/4/62.

SOUTHERN ALBERTA

Student Award Night; 4/26/62.

SYRACUSE

"The Proposed IRE/AIEE Merger," P. E. Haggerty, President IRE; 1/9/62.

"The IRE and the Student," W. Reed Crone, IRE Student Affairs Secretary; 3/15/62.

Panel Discussion on Proposed IRE/AIEE Merger; 4/24/62.

TOKYO

Election of Officers; 4/3/62.

"Broadcasting in Britain an Account of Recent Development," H. Bishop, B.B.C., Britain; 4/11/62.

"Time Aspect of Communications Engineering," W. J. Albersheim, Colombia Univ.; 4/17/62.

TORONTO

Social Evening; 5/7/62.

VANCOUVER

Panel Discussion on IRE/AIEE Merger; Joint with AIEE; 2/19/62.

Joint IRE/AIEE Students Paper Night; After-dinner speaker: Dr. Ashmore, of Vancouver General Hospital on "Open-Heart Surgery"; 3/5/62.

"Plasma Physics," R. Nodwell, Dept. of Physics, U.B.C.; 3/19/62.

Panel Discussion: "The Low Power General Radio Service"; Joint with AIEE; 4/2/62.

WESTERN MASSACHUSETTS

"Using your People Power," E. V. Grumman, Bullard Co.; Joint with Local Technical Societies; 3/21/62.

"Electron Beam Technology," L. McDonald Schetky, Alloyd Corp.; 4/26/62.

WESTERN MICHIGAN

"General Discussion of Oscilloscopes," C. W. Spencer, Techtronix Inc.; 1/10/62.

"Audio and Recording Equipment," R. Mueller, The Radio Bible Class; 2/14/62.

"Clinic On Color TB," J. J. "Jim" Kelly, RCA; 3/14/62.

WICHITA

"Molecular Electronics," S. M. Skinner, Westinghouse Electric Corp.; Joint with AIEE; 4/19/62.

WILLIAMSPORT

"IRE/AIEE Merger Discussion," Prof. Bereskin, Univ. of Cincinnati; 5/8/62.

SUBSECTIONS

EASTERN NORTH CAROLINA

Ladies Night; 3/9/62.

Discussion of Proposed IRE/AIEE Merger; 4/6/62.

MERRIMACK VALLEY

"Advances In Optical Masers," P. J. Miles, Mass. Inst. of Technology; Election of Officers; 4/16/62.

PANAMA CITY

Talk by Mr. H. Williams, Director of Adult Vocational Education; Election of Officers; 4/24/62.

READING

"Project Mohole," S. W. Matthews, Natl. Geographic Society; Joint with Technical Societies Council; 1/23/62.

Tour of Western Electric Plant; Discussion of Proposed IRE/AIEE Merger; 3/21/62.

"Magnetics and Saturable Reactors," G. L. Tawney, Ortho-Magnetics, Inc.; 5/4/62.

SANTA ANA

"Recent Developments in High-Power Electronics and Audio and Radio Frequency Applications," C. G. Pierce, Cameron G. Pierce and Associates, Inc.; 4/10/62.

Panel Discussion: "Why More Women Should Take Up Engineering"; 5/8/62.

SOUTHERN

"Manned Space Flight From Mercury Onward," L. Tinnan, North American Aviation, Inc.; 3/14/62.

Plant Tour—S.T.L., Space Park, Redondo Beach, California; 4/18/62.

VICTORIA

"Some Aspects of the Design and Construction of Television, Television Studios and Transmission Equipment," E. Rose, CHAN-TV; 2/28/62.

"Statistical Analysis of Vacuum Tube Performance in Electronic Equipment," D. McLellan, Pacific Great Eastern Railway; 3/28/62.

(Continued on page 90A)

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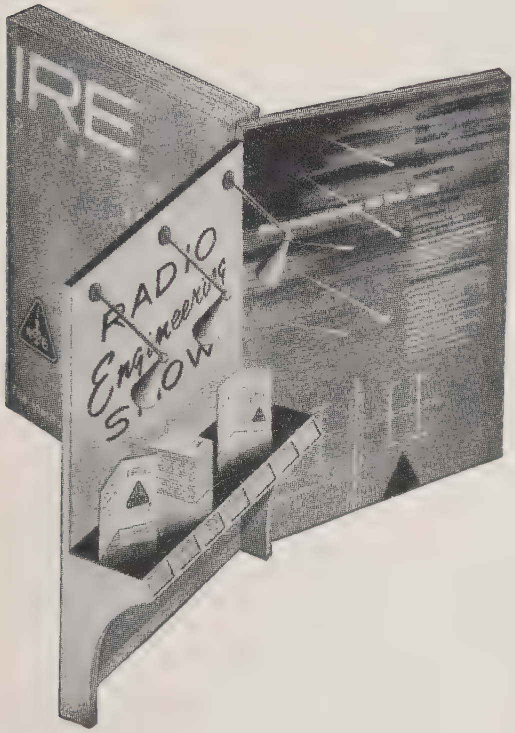

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Section Meetings

(Continued from page 88A)

WESTCHESTER

"Adaptive Servos," H. Chestnut, General Electric Co.; 1/17/62.

"Key To The Spectrum," R. E. Lee, Federal Communications Commission; 2/16/62.

"Digital Robotic Control," L. Jones, Loral Electronics Corp.; 4/25/62.

"Electronics In Inner Space," D. Rebikoff, Loral Electronics Corp.; "Underwater Studies At Great Depths," Dr. Frosh, Hudson Laboratories"; 5/16/62.

Positions Wanted

By Armed Forces Veterans

In order to give a reasonably equal opportunity to all applicants and to avoid overcrowding of the corresponding column, the following rules have been adopted:

The IRE publishes free of charge notices of positions wanted by IRE members who are now in the Service or have received an honorable discharge. Such notices should not have more than five lines. They may be inserted only after a lapse of one month or more following a previous insertion and the maximum number of insertions is three per year. The IRE necessarily reserves the right to decline any announcement without assignment of reason.

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(Continued on page 94A)

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Systems Reliability Analysis

—encompasses the establishment of systems reliability goals if not specified by the customer's requirements. When the customer's requirements define a specific reliability, the allocation of this requirement to the subsystems and lower levels of assembly must be performed. In the performance of this allocation, previous history of similar equipments, state-of-the-art improvement and functional configuration of the system must be prepared. From the detailed functional configuration, the development of mathematical reliability models evolves. The utilization of the developed functional and mathematical models enables predictions of the system reliability to be made.

Evaluation of configuration changes are performed using the established models and with proper costs associated the cost trade studies would be completed.

Design Review

—involves performance of detailed analysis of electrical and mechanical characteristics of each assembly and component to assure optimum reliability. The design reviews require close coordination between design engineering and the reliability engineer.

Evaluation of circuit and equipment designs is conducted to obtain sufficient knowledge of performance of various designs. This evaluation becomes a documented report which encourages the design engineer to utilize the more reliable circuit and/or equipment design.

Component Parts

—includes evaluation of components for utilization by the design engineer, and reliability design review activity. The evaluation takes the form of application notes for the utilization in future designs, with emphasis on derating concepts and establishment of the mode of failure.

Data Analysis

Establishment of data collection, analysis and processing systems. The established data system must be utilized for data from in-plant, field and subcontractors. The analysis of the data takes the form of statistical and analytical reports.

Failure Analysis

An intricate part of the reliability function is to perform or cause to have performed those analyses of failures as are required by applicable specification or customer request.

Liaison and Coordination

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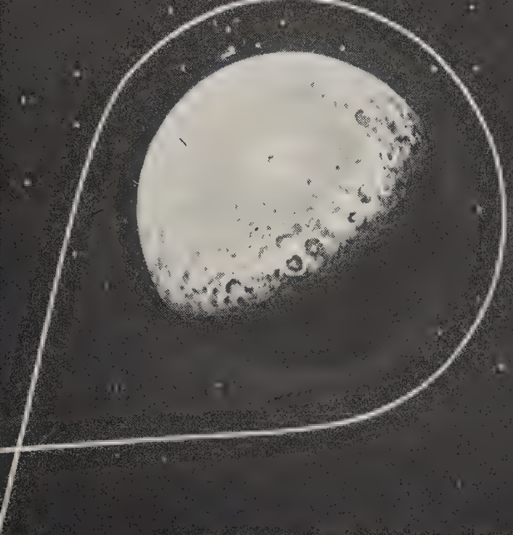

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(Continued from page 90A)

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(Continued on page 96A)

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Engage in research in millimeter wave propagation through solids, higher order mode transmission, and problems involving general electromagnetic theory.

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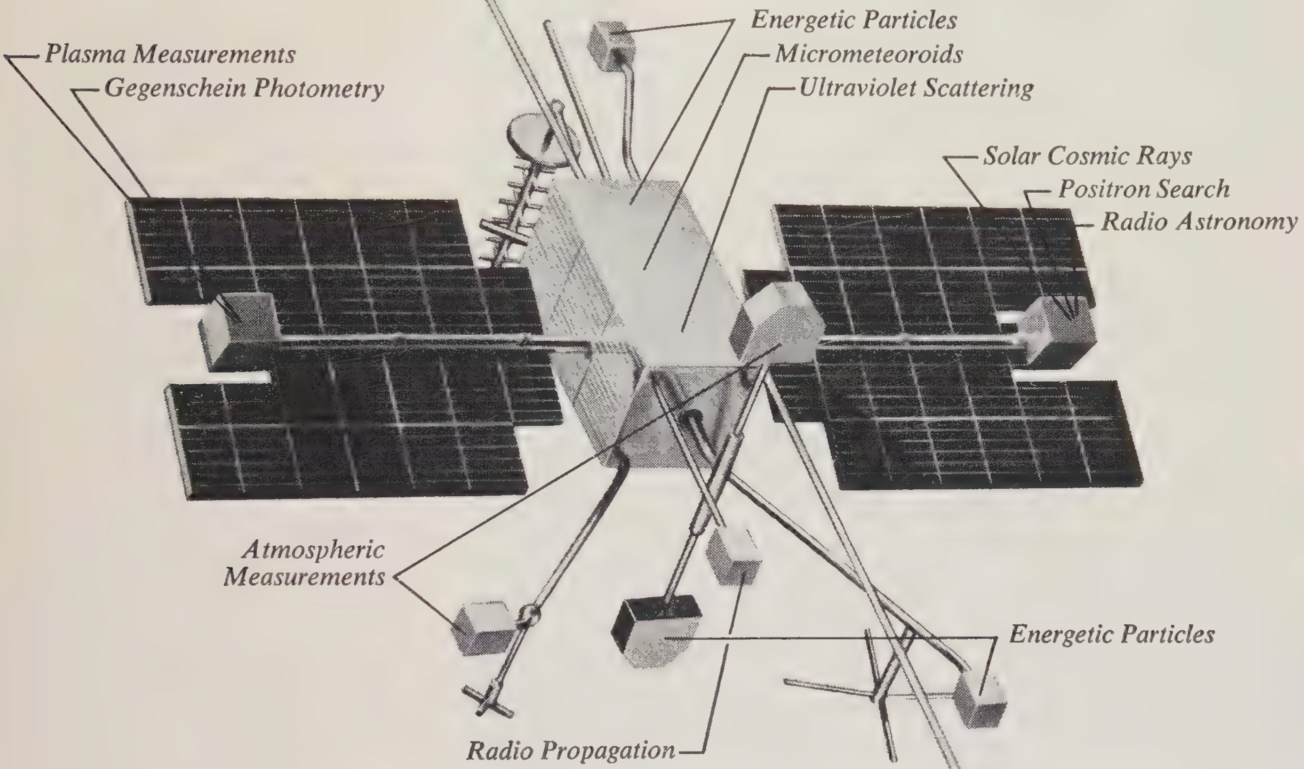
OGO: its first mission. Sometime in 1963, OGO (NASA's Orbiting Geophysical Observatory) will be launched into an elliptical orbit around the earth. It will gather, process and transmit data on the physics of near-earth and cislunar space. Here are some of the studies OGO may undertake in this initial flight: *Energetic particles,* with nine separate experiments on the flux and characteristics of these particles (including cosmic ray and plasma studies). *Radio propagation and astronomy,* through measurements of ambient radio energy not accessible from earth. *Micrometeoroids,* to determine the mass distribution and direction of interplanetary dust in the vicinity of earth. *Magnetic fields,* their intensity, direction and variation near earth and in space. *Atmospheric measurements,* to study the pressure, temperature and composition of earth and cislunar space. *Ultraviolet scattering,* from hydrogen in space. *Gegenschein photometry,* to study sunlight scattered by interplanetary matter. OGO will be launched into a wide range of orbits and may carry as many as 50 different experiments on each of its missions. This Orbiting Geophysical Observatory will be one of the most versatile earth satellites man has ever built.


Magnetic Fields
Energetic Particles
Micrometeoroids
Ultraviolet Scattering
Plasma Measurements
Gegenschein Photometry
Solar Cosmic Rays
Positron Search
Radio Astronomy
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**Captions indicate possible arrangement of instrumentation clusters which OGO may carry.*

OGO: its challenge. Today OGO demands advanced techniques in spacecraft design and development to meet its need for flexibility. It is a challenging responsibility to STL engineers, scientists and supporting personnel, who design it, fabricate it, integrate it, and test it. This versatile spacecraft will be manufactured at STL's vast Space Technology Center where expanding space projects (OGO, Vela Hotel and other programs) create immediate openings for engineers and scientists in fields such as Aerodynamics; Spacecraft Heat Transfer; Analog and Digital Computers; Applied Mathematics; Electronic Ground Systems; Power Systems; Instrumentation Systems; Propellant Utilization; Propulsion Controls; System Analysis; Thermal Radiation; Trajectory Analysis. For Southern California or Cape Canaveral positions, write Dr. R. C. Potter, One Space Park, Department —I, Redondo Beach, California, or P.O. Box 4277, Patrick AFB, Florida. STL is an equal opportunity employer.

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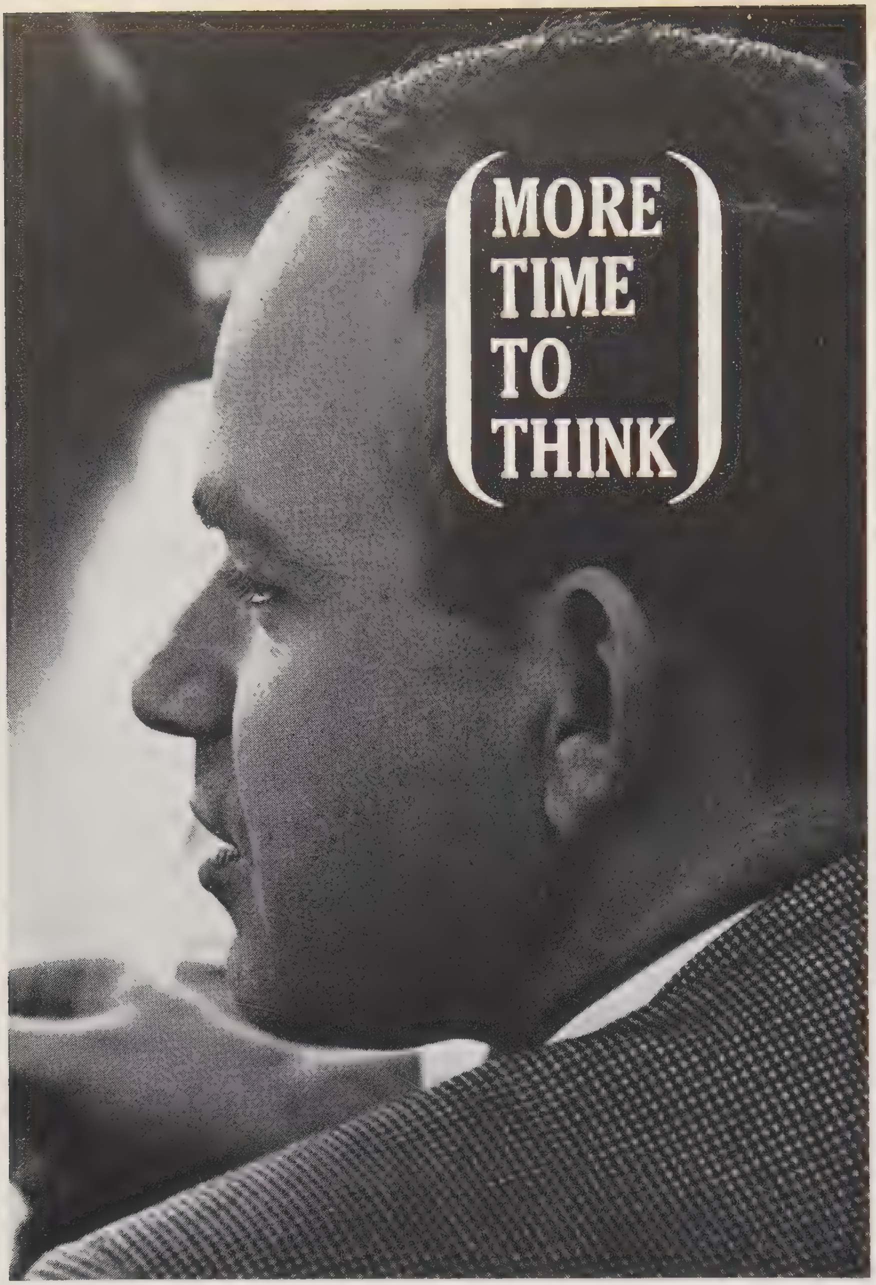

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ORI

Positions Wanted

By Armed Forces Veterans

(Continued from page 94A)

MAINTAINABILITY ENGINEERING

BSEE: MS Experimental Psychology; 8 years experience as electronics technician in military and civilian electronics desires position in maintainability engineering. Anywhere in the world except S. California. U.S. Citizen, formerly held Crypto clearance. Married, available approximately September 10, 1962. Write Box 4008 W.

PATENT/ENGINEER

Examiner, Patent Office, Electro-Mech. Art. Some experience in E.E., Veteran, Navy Electronics, B.S. Physics. Desires position in Metropolitan New York City. Write Box 4009 W.

AUDIO EQUIPMENT DESIGN

BSEE 1958 (Electronics Option), Georgia Tech., age 26, single. Have been on duty in the Air Force since January 6, 1959. Desire ultimate employment in audio equipment design, research & development. Available in June or July 1962. Write Box 4010 W.

ELECTRONIC PACKAGING ENGINEER

Graduate engineer, age 36 with 10 years experience in electronic packaging, development and production of electronic equipment including Air Traffic Control Data Processing; Doppler Navigation Test Equipment. Desire challenging position with growing company in digital field. Write Box 4013 W.

ELECTRICAL ENGINEER

BE & MS in EE. Registered PE, California. 5 years supervisory experience in Navy (LT USNR), including 2 years shipboard and 3 years instructor duty in U.S. Naval Academy in EE. 2 years associated with conduct and administration of industrial technical training on advanced equipment for major firm. Family. Fluent in Spanish. U.S. Citizen. Desire position in engineering in Central America because of family ties. Write Box 4014 W.

Positions Open

The following positions of interest to IRE members have been reported as open. Apply in writing, addressing reply to company mentioned or to Box No.

The Institute reserves the right to refuse any announcement without giving a reason for the refusal.

Proceedings of the IRE
1 East 79th St., New York 21, N.Y.

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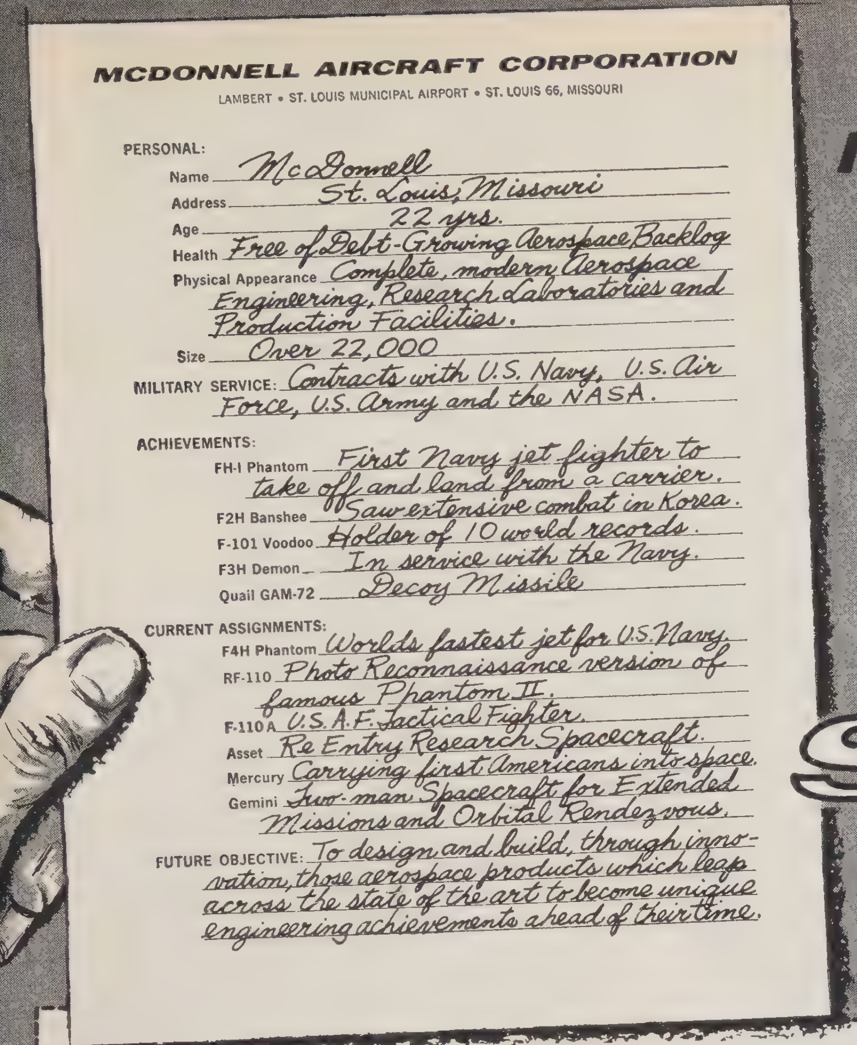
Senior level engineer-physicist—Mathematician needed to direct active and existing program directed toward a better understanding of the fundamental mechanisms involved in sputtering phenomena. Should have experience in the ion bombardment field, and should be familiar with x-ray and electron microscopy as well as ultra high vacuum techniques. Support facilities excellent, subordinate personnel well qualified, and a high degree of freedom to conduct basic research. Send complete resume to Box 2072.

(Continued on page 98A)



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F-101 Voodoo Holder of 10 world records.

F3H Demon In service with the Navy.

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RF-110 Photo Reconnaissance version of famous Phantom II.

F-110A U.S.A.F. Tactical Fighter.

Asset Re Entry Research Spacecraft.

Mercury Carrying first Americans into space.

Gemini Two-man Spacecraft for Extended Missions and Orbital Rendezvous.

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LET'S SWAP RESUMES

Please complete this form and forward to: Mr. D. F. Waters, Professional Placement, Dept. 62, McDonnell Aircraft, St. Louis 66, Missouri. *This is not an application for employment.* Your qualifications will be reviewed by our placement staff and you will be advised of positions at McDonnell for which you qualify. You may then make application if you wish. All replies confidential.

Name________ Home Address________

City & State________ Phone________ Age________

Present Position________

Primary Experience Area________ Number of Years________

Secondary Experience________ Number of Years________

Additional Comments________

Education: AE____ ME____ Math____ Physics____ Chemistry____ EE____ Astronomy____ Other____

Degree: BS____ Date____ MS____ Date____ PHD____ Date____ I would like to receive application form ☐

I would like to receive literature about professional opportunities at McDonnell ☐

My primary interest is:

- ☐ Airborne Communications
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- ☐ Digital Technique and Logic Design
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- ☐ Research
- ☐ Thin Film Techniques
- ☐ Weapons Systems Analysis

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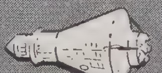

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Write in confidence to Vice President — Technical Operations, The MITRE Corporation, Box 208, Dept. MG4, Bedford, Massachusetts.

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MITRE is an independent, nonprofit corporation working with — not in competition with — industry. Formed under the sponsorship of the Massachusetts Institute of Technology, MITRE serves as Technical Advisor to the Air Force Electronic Systems Division, and is chartered to work for such other Government agencies as FAA.

Positions Open

(Continued from page 96A)

BROADCAST ENGINEER

Long term European assignment with private organization engaged in construction and operation of large high-powered shortwave radio stations. Top qualifications, experience and executive ability desired. Good salary plus overseas benefits. Reply to Box 2073.

TEACHING AND RESEARCH PROFESSORSHIP

Unusual opportunity for electronic engineer or physicist to initiate research program in electronics in rapidly growing urban institution. Income, with research, competitive with industry. Ph.D. or equivalent required. Reply to Dr. T. S. Peterson, Chairman, Division of Science, Portland State College, Portland 1, Oregon.

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Minimum 2 yrs. experience design and audio, power, MIL and industrial transformers. Expanding to multi-plant operations, both coasts. Top salary, full benefits, profit and pension plans. West Coast telephone 213-HO 3-5694; East Coast telephone 516 LOcust 1-6050. Person to contact for interview arrangements, Mr. Richard K. Chaber, Vice President, Engineering, at 516-LOcust 1-6050, Microtran Company, Inc., Valley Stream, N.Y.

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Unique opportunity in small expanding company for a versatile and resourceful man trained in RF techniques, field theory, general electronics, feedback amplifier design and servomechanisms. Development, prototype and initial production runs. Minimum 3 years experience desirable. Reply to Boonton Polytechnic Company, P.O. Box 125, Boonton, New Jersey.

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Staff positions beginning September, 1962. Undergraduate-graduate teaching and research in networks, systems, microwaves, and materials. Write to Joseph C. Michalowicz, Head, Department of Electrical Engineering, The Catholic University of America, Washington 17, D.C.

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Ph.D. with teaching experience to be Department Head. To handle advanced undergraduate courses and to initiate research. College of Liberal arts and sciences. Resume to: R. B. Winslow, Department of Physics, Wheeling College, Wheeling, W.Va.

ELECTRONIC ENGINEERS

B.S. in EE with experience in electron tube and transistor circuits for work on design, development and application of phase measuring instruments. Any nationality. Permanent position. Pleasant working conditions. Salary commensurate with ability and experience. Detailed resume to Ad-Yu Electronics Lab., Inc., 249 Terhune Avenue, Passaic, New Jersey.

RESEARCH EQUIPMENT SALES

B.S. in Physics, EE or ME. Two or more years experience selling specialized mechanical or electro-mechanical equipment (expensive, semi-custom made items). Must be able to understand customers' special technical requirements and work out engineering solutions, such

(Continued on page 100A)

FOR OUTER SPACE . . . THE COG AND THE WHEEL. Program-oriented approach to space age problems lets engineers and scientists at Philco Western Development Laboratories play an important . . . and totally satisfying role in communications and control projects associated with major U. S. satellite programs. The typical Philco WDL program starts with careful analysis of the mission requirements and ends with field activation of equipment, plus test and . . . in many cases . . . continued operation. Thus, the engineer and scientist who begin the project are "on the spot" when theory and advanced techniques become operational equipment. Every cog in the Philco WDL space achievement is an integral part of the wheel.

Write in confidence for information on how you can find your career at Philco WDL, with the additional rewards of ideal living on the San Francisco Peninsula and professional and monetary advancement commensurate with your own ability. Requirements include B.S. or advanced degree (electronics, mathematics, physics), and U. S. Citizenship or currently transferable D.O.D. clearance. Address Mr. Patrick Manning, Department **R-7.**

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OR
Physicists

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Positions also available in our Design and Development area.

Work in suburban Princeton area. Salary comparable to industry. Unusual benefits include 4 weeks vacation and generous retirement plan.

Write to A. C. Allen

ACCELERATOR

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Positions Open

(Continued from page 98A)

as modification of standard equipment to meet requirements. Travel half the time and will work with minimum guidance and support. Must be capable of working with clients on all details including financial. Address your resume to: Mr. Donald Sweet, Arthur D. Little, Inc., 35 Acorn Park, Cambridge 45, Mass. An equal opportunity employer.

MANUFACTURING ENGINEER

Redesign of breadboard models of highly engineered electromechanical equipment for cost reduction and semi-mass production. Experienced in mass and semi-mass production operations. Would build manufacturing competence over an R&D base with a thorough knowledge of the problems involved, i.e., when to modify a design to overcome a problem. Address your resume to: Mr. Donald Sweet, Arthur D. Little, Inc., 35 Acorn Park, Cambridge 45, Mass. An equal opportunity employer.

SENIOR ELECTRONIC SCIENTIST

Electronics Engineer, or Physicist with circuits background, for work in a Research Laboratory. Position will involve application of thermionic, solid state and microwave techniques to measurements and control problems. The person filling this position will work with minimum supervision and carry projects from conception through laboratory or field application. Recent M.S. degree preferred. Send resume and salary requirements in confidence to Personnel Relations Department, Continental Oil Company, Ponca City, Oklahoma.

DEVELOPMENT AND DESIGN ENGINEER

Development and design engineer, for advanced work in electronically regulated power supplies. Must have thorough working knowledge of solid state circuits and feedback systems. Salary to $16,000 according to qualifications and experience. Position offers a career opportunity in a rapidly expanding organization. Apply to Chief Engineer, Kepco, Inc., Flushing 52, N.Y.

TRANSFORMER DESIGN ENGINEER

Transformer design engineer for electronic power supply components and to assist in pioneering development of magnetic type power control devices. Applicant must have a thorough knowledge of magnetic materials and component design. Salary to $16,000 according to qualification and experience. Position offers a career opportunity in an expanding organization. Apply to Chief Engineer, Kepco, Inc., Flushing 52, New York.

ELECTRONIC ENGINEER

A unique position is available for an Electronic Engineer to work in productizing advanced chemical and physical laboratory instrumentation in the field of nuclear magnetic resonance spectroscopy. Succcessful candidate should have a background including at least 5 years experience in electronic circuit design. Position offers outstanding growth potential and individual should have project engineer capabilities. Outstanding benefit program includes Cash Profit Sharing and Stock Purchase Plans. Submit resume in confidence to: Varian Associates, 611 Hansen Way, Palo Alto, California.

SENIOR ELECTRONIC ENGINEER

Excellent position involves working in the experimental and initial development phases of advanced types of commercial scientific instrumentation. Must be willing to work with unusual circuitry and components which often require extending the state of the art. Some background in tube and transistor circuits, radio frequencies, microwave, stabilized amplifiers and other servo problems is desirable. Work will be in close contact with both physics and chemistry. A BS or MS in EE or Physics plus several years experience. Outstanding Benefit Program includes Cash Profit Sharing and Stock Purchase Plans. Submit resume in confidence to: Varian Associates, 611 Hansen Way, Palo Alto, California.

INSTRUMENTAL SCIENCES FACULTY POSITION

All graduate instruction and research. Young Ph.D. Physicist or Electrical Engineer with strong interest in the multidiscipline field of instrumentation and control. Develop courses and research program for M.S. degree and for expansion into Ph.D. program. Twelve month employment. Reply with resume to: Head, Electronics and Instrumentation, University of Arkansas, Graduate Institute of Technology, P.O. Box 3017, Little Rock, Arkansas.

SENIOR STAFF POSITIONS

Openings exist in the area of nuclear instrumentation system analysis. Personnel with (1) an advanced degree in electrical engineering or physics, (2) several years experience in research and development and (3) a working knowledge in data and control systems analysis, statistical information analysis or instrumentation techniques are being sought. The Instrument Development Branch has the responsibility of analyzing and developing data and control systems for nuclear reactors and processes at the AEC National Reactor Testing Station, Idaho. Recent

(Continued on page 102A)

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At Sylvania Electronic Systems the opportunities are nothing less than outstanding. The work is exciting and the advantages of living but thirty minutes from San Francisco speak for themselves. Challenging positions are now available for engineers who want to join us today and be with us at our next stop tomorrow.

SYSTEMS ENGINEERS for reconnaissance systems and subsystems, human factors engineering, operations research and system performance analyses. Five years' experience and background in communications or data processing systems.

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Vitro Laboratories is expanding on all fronts . . . missile systems engineering . . . design and development . . . analysis . . . research and study. We are stretching the parameters of knowledge in space, in the air, on the ground and underseas. We invite you to enter the "go" climate of Vitro.

Vitro is a good place to work. Here you will find a professional atmosphere conducive to original and imaginative thinking. Skilled clerical and technical support frees you to concentrate on the creative aspects of your assignments, and salaries are at a level worthy of your attention. You will advance as fast as your talents allow.

Career appointments are available immediately in the following areas:

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ANALYSIS
Radar and IR systems
Digital and analog equipment
Fire control systems
RESEARCH & STUDY
Reliability and feasibility studies
Basic and applied research
Weapons systems analysis
Acoustic studies
ASW studies

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Manager, Professional Employment

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Silver Spring, Maryland
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Positions Open

(Continued from page 100A)

and future expansions have created outstanding opportunities. Write: Philips Petroleum Company, Personnel Administration, P.O. Box 2067-HN, Idaho Falls, Idaho.

CRITICAL VACANCIES AT GRIFFISS AIR FORCE BASE, ROME, NEW YORK

Electronic Engineer	GS-7	$6345 pa.
Industrial Engineer	GS-7	$6345 pa.
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Mechanical Engineer	GS-9	$7095 pa.
Research Psychologist (Engr.)	GS-9	$6435 pa.
Electronic Engineer (Electro Mag)2	GS-11	$8340 pa.
Electronic Engineer (Gen.)	GS-11	$8340 pa.

COMMUNICATIONS FOREMAN

U.S. Oil Company, operation Middle East, seeks foreman with FCC or International Radio Telephone and Radio Telegraph First Class to supervise complete communications system with diversified equipment (AM, FM, HF, VHF, Teletype Printer, 100 Line PABX, Multichanneling, etc.) Candidate must have thorough background Electronic Theory with ten years practical experience (2 to 3 years Supervisory Experience). Approximately $11,600/year which includes $204 month Field Living Allowance; Bachelor Status; 30 day annual vacation with transportation paid; Savings Plan. No U.S. or Foreign Income Tax. Send Resume to Box 2074.

SENIOR PROJECT ENGINEERS

Immediate openings available for Electrical Engineers with Solid State Circuit design experience. Must be capable of assuming project administrative responsibilities. Will handle technical liaison activities wth outside contractors. Be capable of directing in-house design effort, component evaluation, and subsystems tests. Masters degree in Physics or Electrical Engineering desirable, but will accept Bachelors Degree with record of solid project achievement. An Equal Opportunity Employer. Send complete resume to Jet Propulsion Laboratory, 4804 Oak Grove Drive, Pasadena, California.

IRE People

(Continued from page 56A)

Microwave Associates, Inc., announced the appointment of **Dr. Matthew Allen** (S'56–M'59) as Manager, Plasma Physics in the Tube and Component Division. Dr. Allen will be engaged primarily in beam-plasma amplifier research and development and high power studies.

M. A. Allen

Since 1959, Dr. Allen has been engaged in post-doctoral research in high-power microwave tubes and basic plasma physics at the Microwave Laboratory of Stanford Uni-

RESEARCH ENGINEERS AND SCIENTISTS

ADAPTIVE PATTERN RECOGNITION... A system conceived by Sheldon Akers and associates at the Electronics Laboratory adaptively organizes its internal logic circuits as it is fed binary samples of a pattern in its various forms. The letter "A" for instance may be large, small, rotated, translated, with and without serifs, etc. • Through a prescribed algorithm, the adaptive system ultimately establishes a network of threshold logic gates capable of recognizing the pattern in whatever form it appears. Simulation has been accomplished by means of a computer program. Several pattern recognition trials have been run with results that far surpass those of random—or heuristic—recognition networks.

Can You Define Boundaries for Electronics ?

• Investigators at General Electric's Electronics Laboratory believe that no technology is so "remote" that it may not one day contribute to advances in one of the diverse areas conveniently labeled "electronics" today. The result of this philosophy is an enriching collaboration among individuals from many fields. The above abstract indicates one of the many areas of interest under investigation by staff members. Scientists and engineers (with PHD, MS, or BS degrees) attracted by a multidisciplinary intellectual climate, are invited to inquire about *opportunities to explore new approaches to:*

SOLID STATE DEVICES. MICROELECTRONIC CIRCUITRY. ELECTRONICALLY FUNCTIONAL THIN FILMS. DATA PROCESSING TECHNIQUES USING THEORIES OF AUTOMATA, ADAPTIVE SYSTEMS. PHYSICAL PHENOMENA WITH POTENTIAL FOR MICROWAVE AND COHERENT OPTICAL DEVICES. NON LINEAR AND ADAPTIVE CONTROL SYSTEMS. MATERIALS AND PROCESSES (INORGANIC & ORGANIC CHEMISTRY) • *Write in confidence to:* Mr. Richard J. Sullivan, Dept. 53G, General Electric's Electronics Laboratory, Electronics Park, Syracuse, New York.

ELECTRONICS LABORATORY

GENERAL ELECTRIC

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versity. His most recent activity concerned experimental and theoretical investigation of beam-plasma amplification.

Dr. Allen received his Bachelor's degree in physics from the University of Edinburgh in 1951, and his Doctorate degree in physics from Stanford University in 1959.

He served two years with the REME Corps of the British Army as a Radar Officer.

Dr. Allen is the author of several papers in the field of microwave physics. He is a member of the American Physical Society and Sigma Xi.

⁂

Power Designs, Inc., Westbury, N. Y. recently announced the appointment of **Alfred A. Goldberg** (M'61) as Vice-President-Sales. Mr. Goldberg has been associated with the Electronic industry for over twenty years.

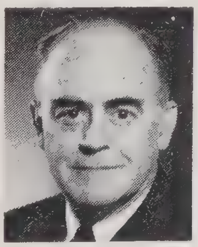
A. A. GOLDBERG

In his new position, Mr. Goldberg will be responsible for both the commercial and military sales and marketing program. Prior to joining Power Designs, Inc., he was Sales Manager of Polarad Electronics Corp., and before that, with CBS-Columbia as Assistant General Manager of Defense Operations.

A graduate of the Polytechnic Institute of Brooklyn, Mr. Goldgerg is a member of Pi Tau Sigma, Honorary Mechanical Engineering Fraternity. He is currently implementing a program of national and international sales and service, coordinating with sales representative organizations with local stocking of equipment to provide expanded customer liaison in order to assure quick reaction to customer requirements.

⁂

Thomas J. Killian (A'47–SM'47–F'51) has recently accepted the position of Assistant to the President in Science and engineering at Seattle University, Seattle, Wash.



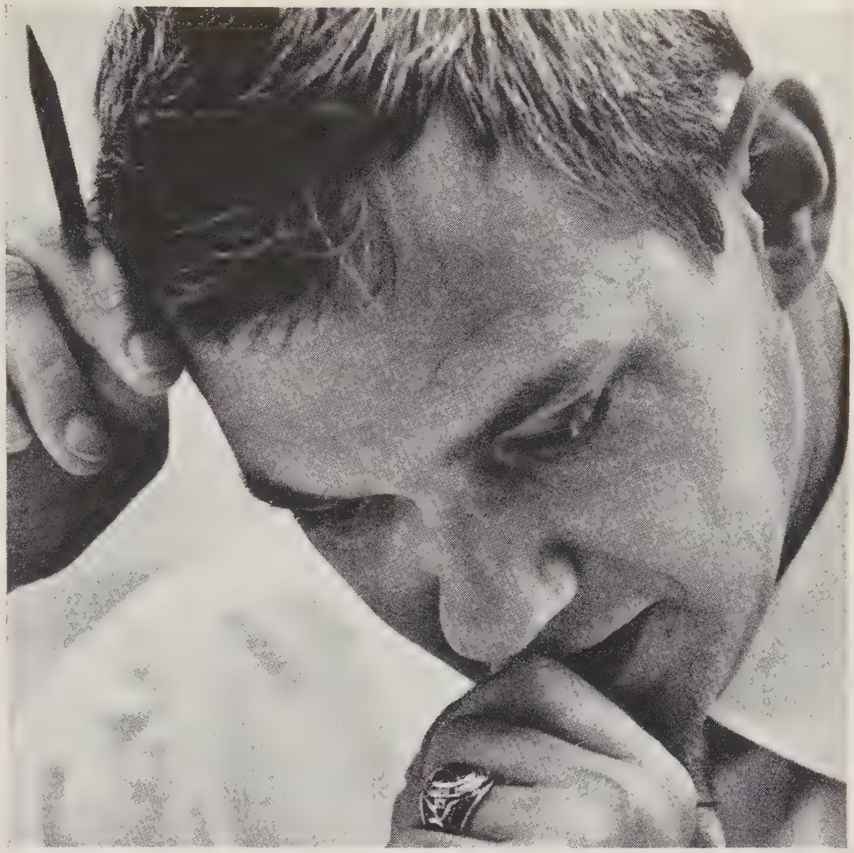
T. J. KILLIAN

He received his B.S. and M.S. degrees in electrical engineering from the Massachusetts Institute of Technology in 1926. In 1927 he earned his A.M. degree in physics and his Ph.D. degree in 1929, both at Princeton University.

From 1955 to 1961 Dr. Killian was Deputy Chief and Chief Scientist for the Office of Naval Research. Prior to this he was Dean of the School of Engineering and Architecture at the Catholic University of America, Washington, D. C. From 1952 to 1954 he was Chief Scientist for the Office of Ordnance Research (now Army Research Office) at Duke University, and in 1954 he

(Continued on page 104A)

Wanted: Men who cannot curb their curiosity



Northrop Space Laboratories is a new organization, open to fresh viewpoints and new ideas. Its greatest need now is for men like you; men with a driving urge to find out things for themselves. You'll help to point out the directions we'll go in the exciting years ahead. Come in now and grow along with us. The following key openings are immediately available:

Solid state physicists, to conduct fundamental research on many-body problems as applied to an ultra high pressure program. The goals of this program are to study the electrical and physical behavior of materials under ultra high pressure, to investigate the origin, history and structure of the moon and planets, and to find ways to utilize their natural resources.

Scientists, to perform research in nuclear and radio-chemistry, and to conceive and carry out investigations in the fields of activation analysis, dosimetry, gamma ray spectrometry, surface phenomena, and numerous other areas.

Structural engineers, to do stress analysis and optimize the design of advanced space structures.

A plasma physicist, to join our growing program in the measurement of plasma properties, spectroscopy, diagnostics, accelerators, and power conversion devices.

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IRE People

(*Continued from page 103A*)

was Consultant for the Office of Operations Research, U. S. Army.

Dr. Killian is a member of the Standing Committee of Federal Council for Science and Technology; International Committee for FCST; Committee on Science of DDR&E; IGY and Satellite Committee. He is a member of the American Physical Society, A.A.A.S., A.I.E.E., Illuminating Engineering Society, A.S.E.E., Operations Research Society of America, Naval Institute, Philosophical Society of Washington, Navy League, W.A.S., Sigma Xi, Tau Beta Pi, and Phi Kappa.

Dr. Killian has had numerous papers published and holds four patents.

❖

Dr. Alexander A. J. Hoffman (S'54-M'61), Senior Physicist with the University of Texas Defense Laboratory since 1960, has been named Director of Computer Center and Assistant Professor of Mathematics at Texas Christian University.

A New York native, Dr. Hoffman holds his B.A., M.A. and Ph.D. degrees from the University of Texas. He was a special instructor in mathematics there from 1956–1960.

Dr. Hoffman is a member of Sigma Pi Sigma, physics honor society; American Physical Society; Texas Academy of Science; American Mathematical Association; and other professional organizations.

He is a Korean veteran, member of B'nai Brith, and the author of several articles on physics and related fields in national journals.

❖

Linder C. Hobbs (S'47–A'50–M'55) has left Aeronutronic, Division of Ford Motor Company, to form the consulting firm of Hobbs Associates.

Mr. Hobbs' firm will cover an area ranging from developing the specifications to meet stated systems requirements through final detailed design of a digital system.

At Aeronutronic, Mr. Hobbs was Manager of Data Processing Engineering. Included among his many responsibilities were proposal preparation, equipment marketing, product planning and the responsibility for determining specifications, design, development, fabrication and check-out of all types of digital equipment.

Prior to joining Aeronutronic in 1957, he spent three years in a supervisory capacity with Remington-Rand UNIVAC, and prior to that was a project engineer for RCA.

He has been a lecturer in engineering at U.C.L.A. since 1957.

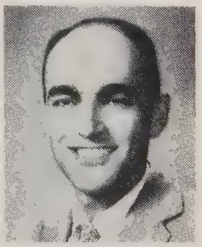
His professional association affiliations include the Association for Computing Machinery, and the American Ordnance Association. He has held numerous offices and positions of responsibility in the Institute of Radio Engineers.

He received his Bachelor's degree in electrical engineering at Georgia Institute of Technology in 1948. He earned his Master's degree in electrical engineering at the Moore School, University of Pennsylvania, in 1952 and a Master's degree in business administration at the Wharton School in 1956.

Hobbs has had five patents granted and has ten patent applications pending. He is presently editing a textbook titled "Digital Systems Design."

❖

Richard O. Endres (S'46–A'49–M'53–SM'55), whose resignation as President of Rese Engineering was recently announced has formed a new company—the Computer Instrumentation Corporation.



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❖

(*Continued on page 106A*)

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SENIOR DESIGN ENGINEERS

BS with 8 years experience, of which 5 must have been in design in two or more of the following: digital, RF, pulse, audio, CRT, photorecorders, magnetic recorders, pulse multiplex and frequency multiplex. To assist in evaluation of complex electronic reconnaissance systems.

DESIGN ENGINEERS

BS with 3 to 5 years experience in RF and microwave receivers, digital display circuits, data handling and CRT displays including storage tube circuits. To assist in evaluation of complex electronic reconnaissance systems.

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SENIOR DESIGN ENGINEERS

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IRE People

(*Continued from page 104A*)

Organization of the management staff for planning and programming at General Dynamics/Electronics, Rochester, N. Y. has been completed. **William L. Bayer,** (SM'56) Director of Programs Coordination, and **Stanley E. Benson** (A'33–M'55), Manager of Long Range Planning, will both be reporting directly to the President.

S. E. Benson

Mr. Bayer joined General Dynamics/Electronics (then known as Stromberg-Carlson), in 1957. He attended Haverford College, prior to appointment to the U. S. Military Academy in 1922. He received a Bachelor of Science degree from the Academy, and later earned a Master of Science degree in communications engineering from Yale University. He served in the U. S. Army Signal Crops for 30 years, and retired in 1956 with the rank of Brigadier General.

Mr. Benson has been with General Dynamics/Electronics since 1960, when he joined the former Military Products Division as Systems Staff Manager. Previously he had served on the technical staff of the Advanced Research Projects Agency in the Department of Defense, and earlier held engineering and managerial positions with the Philco Corporation, the New York Telephone Company, and other firms. He has a Bachelor's and Master's degree from Rensselaer Polytechnic Institute, and is a member of Sigma Xi.

⁂

James J. Lamb (A'28–SM'48–F'54) was recently sworn into his newly assigned position as Scientific Advisor and Director of the Signal Communications Department, Fort Huachuca, Ariz.

J. J. Lamb

Mr. Lamb, who had been employed by Ramo Wooldridge Division of Thompson Ramo Wooldridge, resigned to accept his new position under Public Law 313 which Congress passed to establish criteria to appoint selected scientists and engineers to positions of high responsibility.

He graduated from the Michigan, N. D. High School in 1918 and later attended the University of Minnesota and the Catholic University of America in Washington, D. C., where he earned a B.S. degree in electrical engineering. He

(*Continued on page 108A*)

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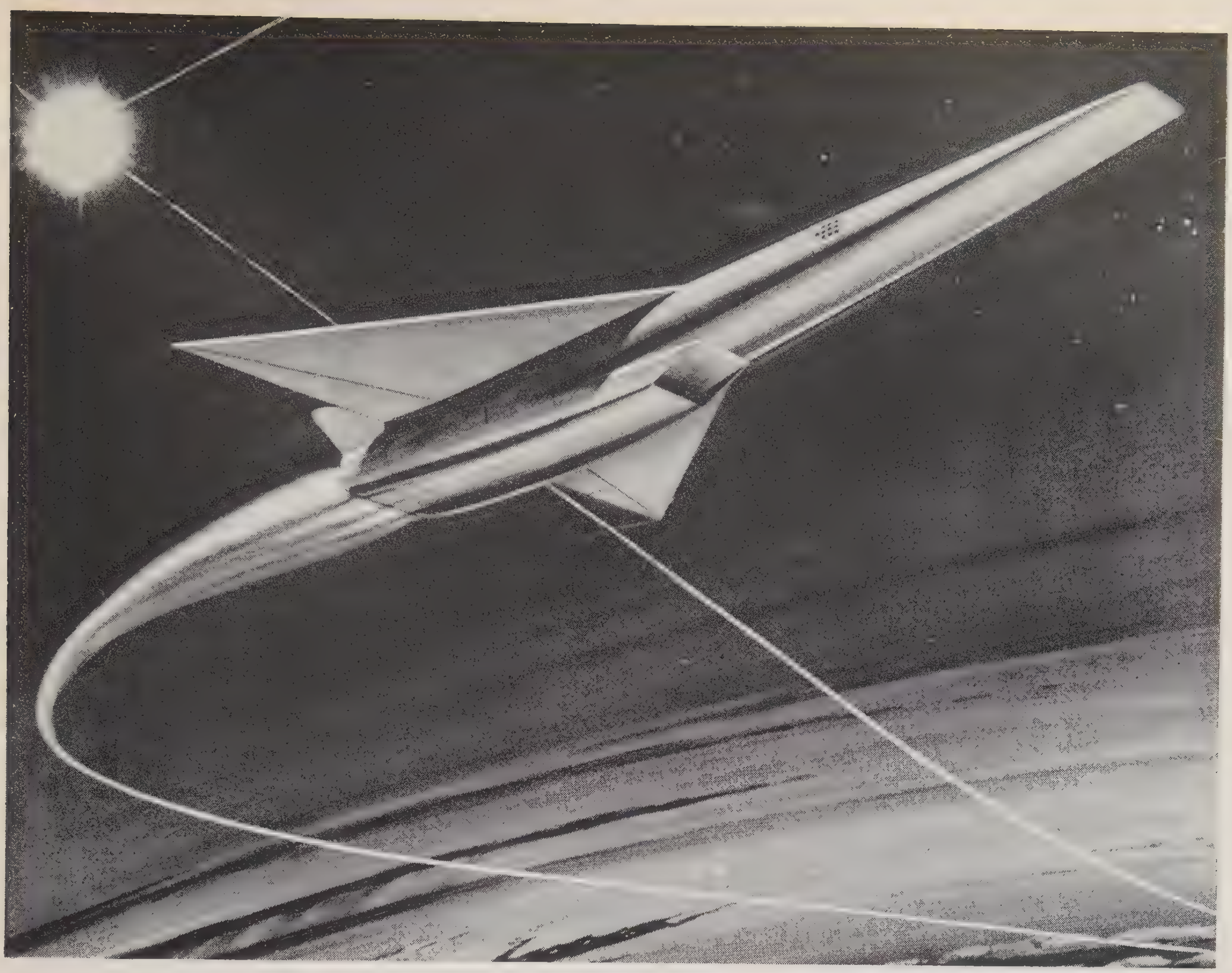

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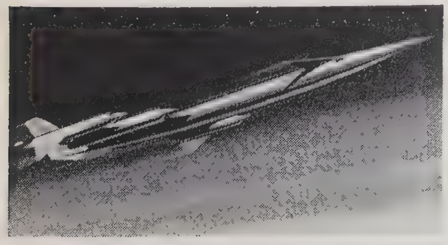

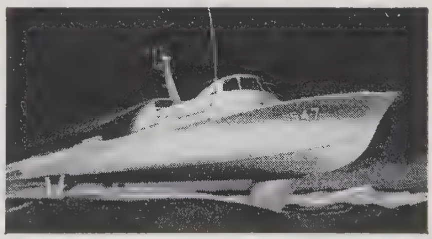

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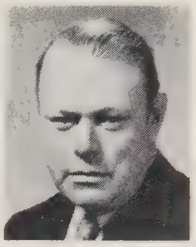
(Continued from page 106A)

also attended Georgetown Law School in Washington and the University of Connecticut where he received a certificate in industrial management.

He was also awarded the National Defense Research Committee Certificate in 1945 and the American Radio Relay League Merit Award in 1959.

❖

Dr. K. C. Black (M'29–SM'43–F'49) President of the Scientific Analysis Corporation will be the banquet speaker at Colorado State University's fifth annual Institute in Technical and Industrial Communications July 9–13, 1962.


K. C. Black

Dr. Black received the Ph.D. degree in physics from Harvard University. After entering the university at the age of fifteen, he taught physics at Harvard until 1929 when he left the teaching profession to enter industry. After working a year in the Boonton Research Laboratories, he took a position with the Bell Telephone Laboratories where for the next twelve years he was concerned with the development of electronic transmission. In 1943 he left Bell Laboratories to join the staff of Aircraft Radio Corporation where he remained until 1947.

Since 1947, Dr. Black has held many positions of a scientific nature with both industry and the armed forces. In the summer of 1956 he worked on a Weapons Systems Evaluation Group study in a classified nature, which was conducted for the benefit of the Joint Chiefs of Staff. In 1957 he visited Europe on a mission for the Mutual Weapons Development Program.

Dr. Black has served on the IRE National Board of Directors, and has done considerable work in Professional Group activities. From October, 1957, until November, 1960, he had the position of Science Advisor to the Supreme Allied Commander in Europe, with headquarters at SHAPE, near Paris.

❖

Dr. Samuel Koslov (A'55–M'60) was appointed Chief, Physical Sciences, by Allied Research Associates, Inc. to coordinate and direct the Physical Sciences Department. Dr. Koslov will be responsible for the physics, chemistry and biosciences activities of Allied Research.

Dr. Koslov's research has been primarily in plasma and nuclear physics. In

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plasma physics he has been concerned with the acceleration of plasmas to high velocities, the interaction of plasmas with magnetic fields and other plasmas, and the study of controlled thermonuclear fusion reactions. At Stevens Institute of Technology he was principal investigator on the Chalice Program for cusp containment of high temperature plasma and started the program with which he is still associated on the utilization of chemical explosions to produce plasma by collision of shape charges. At Stevens he was Associate Professor of Physics and Assistant Head of the Physics Department. During this time he also served as consultant to Vitro and Republic Aviation.

He was associated with the Vitro Engineering and Vitro Laboratories divisions of Vitro Corporation where he was concerned with the study of nuclear reactors and nuclear weapons effects. Prior to this he was a member of the technical staff of the Bell Telephone Laboratories.

Dr. Koslov was a research assistant at the Nevis Cyclotron Laboratories of Columbia University from 1950–1954. While there, he completed his doctoral thesis on "Studies of Low Energy Mesonic X-Ray Transitions and Vacuum Polarization Effects in Mesonic Atoms." His Ph.D. degree was earned from Columbia in 1957, in physics. He gained an A.B. degree from Columbia College in 1948, and a Master of Arts degree in physics in 1950 at Columbia.

He is a member of the American Physical Society, Phi Beta Kappa, Sigma Xi, American Geophysical Union, and the American Rocket Society. He was Vice President of the New York Section of ARS from 1960–1962.

◆

Jaap M. Unk (SM'61) and **Jan Piket** (SM'60) have recently been appointed Director and Associate Director, respectively, of the newly established consultant firm Information Systems Inc., Den Haag, Netherlands. The firm provides consulting services on the organization and composition of complex data processing systems.

J. M. Unk

J. Piket

Mr. Unk retired in 1961 from his position as a Director of the Philips Telecommunicatie Industrie, Hilversum, after having devoted his entire career since 1920 to the Philips organization. After graduating in 1925 in electrical engineering from the Technische Hogeschool at Delft, he worked in the Philips Research Laboratories in Eindhoven, and became Chief of the Receiver Research Laboratory in 1930. He developed the first European allmains

(Continued on page 110A)

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(Continued from page 109A)

commercial receiver in that period. From 1932 to 1938 he held various positions concerned with manufacturing, management, and industrial organization. He also assisted in setting up radio factories in Switzerland, England, Czechoslovakia, and Argentina.

From 1948 on Mr. Unk stayed with PTI being initially in charge of all designed departments, still giving much personal attention to electrical and mechanical design, but shifting gradually from commercial to professional equipment. He took an active part in developing new telephone and telegraph centers, and in 1954 was appointed Associate Manager for Telephony and Telegraphy. In 1958 he transferred his activities entirely to data transmission and data processing, paying special attention to the development of airline reservation systems and to integrated data processing for bank administration.

From 1946 to 1958 he held the post of Special Professor at the Technische Hogeschool, Delft, where he lectured on the engineering of telecommunication equipment.

Mr. Piket resigned in 1960 as Director of the SHAPE Air Defence Technical Centre, Den Haag, Netherlands, terminating a period of some 20 years in defense research, with a brief interruption during World War II, when he was assigned to the Netherlands P.T.T.

After graduating in 1935 from the Department of Applied Physics of the Technische Hogeschool at Delft, he joined the Physics Laboratory of the Netherlands Ministry of Defense, which after the war came part of the Netherlands Defense Research Organization. His first years were spent on research in infrared and electromagnetic radiation and on military instrumentation. The last two years before the war he assisted in the development of a radar set.

When the Physics Laboratory was reestablished, on a larger scale, after the war, Mr. Piket was appointed Deputy Director. A good deal of his personal attention was devoted to the threshold sensitivities of various electromagnetic detection devices. In addition he was responsible for making the initial design of an intermediate air force control and reporting system, using analog techniques.

When in 1954 the United States Air Force contracted with the Netherlands Defense Research Organization for the establishment and subsequent initial operation of the SHAPE Air Defence Technical Centre, he was selected to be the first Director. During his period of responsibility SADTC grew to a position of established technical competence on international defense matters in NATO. It contributed to international military scatter communications, to the design and standardization of modern digital control and reporting systems, and to the evaluation of weapon systems for air defense.

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(Continued on page 112A)

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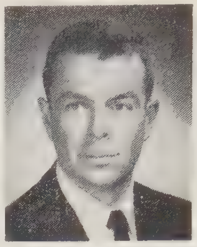
(*Continued from page 110A*)

Dr. John L. Sprague (M'60) has been elected to the Board of Directors of the Sprague Electric Company, North Adams, Mass.



J. L. Sprague

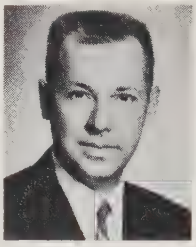
He currently heads the Transistor Research Department of the Company's Research Laboratories.

Born in Boston, he received the Bachelor's degree from Princeton University and the Ph.D. degree in physical-inorganic chemistry from Stanford University. He served for three years as an officer with the U. S. Navy, and was Assistant Electronics Officer and Electronic Division Officer on the experimental electronics cruiser USS Northampton.

Dr. Sprague is a member of the American Chemical Society, and Electrochemical Society.

❖

The appointment of **Dr. Carl E. Faflick** (S'50–A'54) as Director of the Advanced Systems Planning Organization of Sylvania Electronic Systems, has recently been announced.



C. E. Faflick

In his new capacity, Dr. Faflick will examine long-range military systems concepts, areas of technical interest, and will conduct planning studies to determine appropriate division emphasis to satisfy military needs.

Dr. Faflick joined the division as an engineering specialist in 1953. He was Manager of the Antenna and Microwave Laboratory within the Division's Waltham Laboratories before his present appointment.

Prior to joining Sylvania, he was a Research Fellow at Harvard University for four years. He also served as an instructor at New Mexico State College for one year.

Dr. Faflick received a Bachelor's degree from Oberlin College, Ohio. He subsequently served with the U. S. Army Signal Corps for three years, and attended a radar officers training course conducted jointly by Harvard University and Massachusetts Institute of Technology.

He received a Doctor's degree in applied science from Harvard in 1953. While at Harvard, he received a Sheldon traveling fellowship, which provided additional study at the Swiss Federal Technical Institute, Zurich, Switzerland.

He is a member of Sigma Xi, and for-

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★ SYSTEMS TEST

★ OPERATIONAL EVALUATION

The Applied Physics Laboratory is responsible for the operational evaluation of the Polaris submarine and missile system. APL also has full responsibility for the Navy's Terrier, Tartar, Talos and Typhon guided missiles from conception through design development, and shipboard test and evaluation.

Additional staff members are urgently needed to satisfy the requirements of these programs. Respondents must have a degree in engineering or physics and at least five years' experience in radar, navigation, fire control, instrumentation, missile system test, or missile system simulation.

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Appointments

The Applied Physics Laboratory
The Johns Hopkins University

8603 Georgia Avenue,
Silver Spring, Md.
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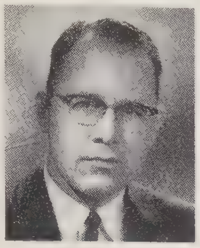
(Continued from page 112A)

mer Chairman of the Professional Group on Microwave Theory of the Boston Chapter of IRE.

❖

Virgil W. Wall (S'48–A'50–M'55–SM'56) has been appointed as Chief Engineer of Omega Dynamics, Inc., Pasadena, Calif.



V. W. Wall

Mr. Wall's prior affiliations include positions as Director of Engineering, Telecomputing Corporation; Manager, Advanced Development, Raytheon Manufacturing Company; Chief Engineer, G. M. Giannini and Co.; Supervisor, Radar, North American Aviation, Inc.; and as a member or the technical staff of Bell Telephone Laboratories.

He holds a B.S. degree in electrical engineering from Pennsylvania State University, and a M.S. degree in mathematics and physics from Stevens Institute of Technology.

Patents held by Mr. Wall are in the fields of vacuum tube, radar and navigation systems. He is a registered professional engineer in the State of California and a member of AIEE, and ARS.

❖

Dr. Charles Concordia (SM'55), General Electric Company, Schenectady, N. Y., has been named the recipient of the 1961 Lamme Medal by the American Institute of Electrical Engineers. The Medal is one of the major awards of the engineering profession.

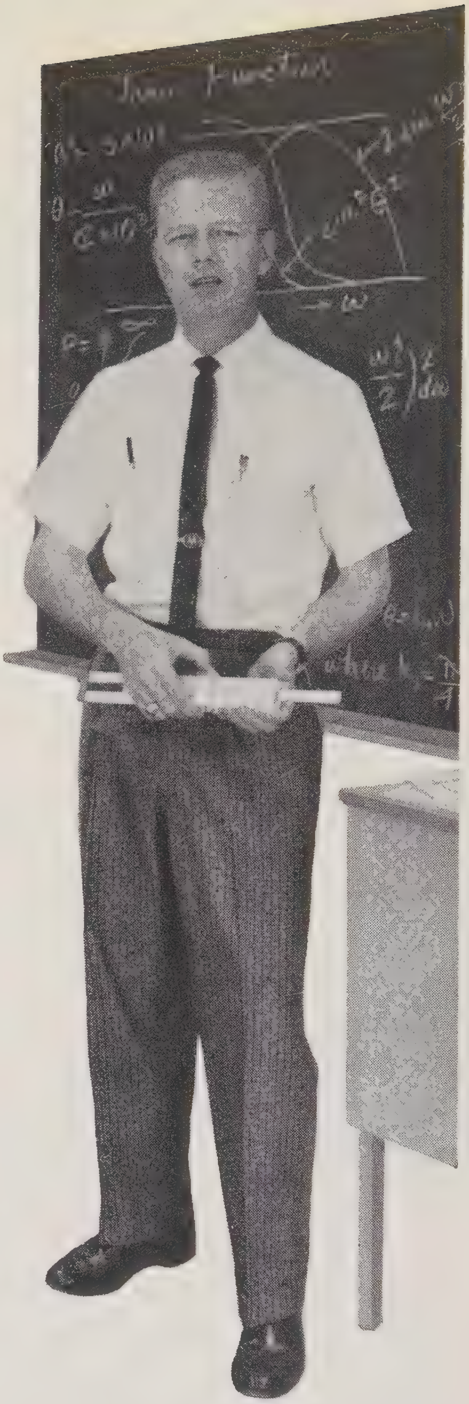
C. Concordia

Dr. Concordia, Manager, General Analytical Engineering, for General Electric, was cited "For meritorious achievements in the design of electrical machinery; more specifically, for analyses of synchronous machine characteristics leading to improved designs and for exceptional contributions to the application and control of machines used in electric power systems."

The Medal was established to honor a member of AIEE "who has shown meritorious achievement in the development of electrical apparatus or machinery."

Dr. Concordia is a native of Schenectady and has been with G.E. since 1926. He was in the General Engineering Laboratory originally, but transferred to the Electric Utility Engineering Operation in 1936.

(Continued on page 114A)



Engineers and scientists who are willing to assume responsibilities—who seek challenging assignments and the opportunity to prove their leadership — are the kind who fit at Motorola in Phoenix. Noted as a sound, stable military electronics organization with an outstanding record of healthy growth, Motorola is broadly diversified, which provides a wide choice of state-of-the-art projects to work on . . . and lots of "growing room." Most of all, we're proud of our reputation for providing job stability.

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Develop microwave circuits and equipment including wave-guide assemblies, and related circuits.

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Develop radar transmitters and modulators including pulse forming networks, transformers, protection circuits, X-band amplifiers and related circuits.

Display and pulse circuits. Develop display circuits and controls. Bomb navigation cross hair circuitry.

SR. DESIGN ENG'RS.

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SR. PACKAGING ENG'RS.

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IRE People

(Continued from page 113A)

In 1942, he received the G.E. Coffin Award. He is the author of more than sixty-five technical papers and of a book on synchronous machines. He holds six patents in the fields of Automatic inspection, automatic control, rotating machinery, electric power systems and centrifugal compressors

Dr. Concordia has been very active in AIEE and other technical societies. In AIEE, he has been a member of the following committees: Basic Science; Computing Devices, First Chairman; Transfers, Chairman; Periodicals and Transactions; Admissions and Advancement Department; and Science and Electronics Division. At present he is Vice Chairman of the Board of Examiners and a member of the Research Committee and the Publications Department.

He is a Fellow of AIEE and of The American Society of Mechanical Engineers, a member of the National Society of Professional Engineers and a charter member and former national Treasurer of the Association for Computing Machinery. He recently was appointed Chairman of the International Study Committee on Power System Planning and Operation of CIGRE.

⁂

Terence R. Gregory (M'55–SM'61) has been elected President and Director of DATA-tronix Corp., Norristown, Pa.

As President of DATA-tronix, Mr. Gregory will be responsible for the general administration and technical direction of the company.

T. R. Gregory

He received his B.S. degree in electrical engineering from Borough Polytechnic Institute, London, England in 1949. He became a Chartered Electrical Engineer in 1950. Post graduate courses were completed at both the Northampton Polytechnic Institute, London, and the University of Pennsylvania.

Mr. Gregory was formerly a Vice President and General Manager of the TELEdatax Division, Sonex, Inc., Philadelphia. He was a Group Supervisor at Teledynamics, Inc. where he was responsible for the design of telemetry components and systems for the Boeing Bomarc missile. As Staff Engineer at Clifton Precision Products Co., Clifton Heights, Pa., he designed navigational and automatic dead-reckoning systems. He has designed and developed new techniques for programming electronic analog computers in Britain, Canada and the U. S., and also served as an RAF technical instructor for two years.

He is a member of the Franklin Institute, and Graduate IEE, England. He is

(Continued on page 116A)

COLLINS CALL

FOR SCIENTISTS & ENGINEERS

EQUIPMENT DEVELOPMENT

BSEE — Elec. Eng. — 3 yrs. exp. HF or VHF (CR or D)

BSEE — Elec. Eng. — 3 yrs. exp. Automatic Test and Checkout (CR or D)

BSEE — Elec. Eng. — 6 yrs. exp. Power Servo Design (CR)

BSEE — Elec. Eng. — 3-5 yrs. exp. UHF (CR or D)

BSEE — Elec. Eng. — 3 yrs. exp. Command Control Systems (CR)

BSEE — Elec. Eng. — 3 yrs. exp. Radar Beacon Work (CR)

BSEE — Elec. Eng. — 3 yrs. exp. Television Transmission (CR)

BSEE — GSE Supervisor — 5 yrs. exp. Equipment Development (CR)

BSEE — GSE Eng. — 3 yrs. exp. Ground Support (CR)

BSEE — Digital & Logic Design — 2-5 yrs. exp. (D)

BSEE — Circuit Design — 1-5 yrs. exp. (D)

BSEE — ECM — 2-5 yrs. exp. (D)

SYSTEMS

MSEE — System Analyst — 5 yrs. exp. Modulation Technique (CR)

MSEE or equiv. — System Analyst — 5 yrs. exp. Tracking and Ranging (CR)

MSEE — System Analyst — 5 yrs exp. Communications (CR)

BSEE minimum — GSE Integration Supervisor — 5 yrs. exp. Ground Support (CR).

MS or equiv. in Physics or Mechanics — System Analyst — 3 yrs. exp. Classical or Celestial (CR)

BS — Field Supervisor — 5-10 yrs. exp. Airborne Electronics and Communications (CR)

BS or equiv. in EE — Field Eng. — 3-5 yrs. exp. Com. (CR)

BSEE minimum — GSE Layout Eng. — 5 yrs. exp. Layout (CR)

BSME or equiv. — Mech. Eng. Supervisor — 8-10 yrs. exp Management and Administration (CR)

BSME or equiv. — Mech. Eng. — 3-5 yrs. exp. Packaging Designs (CR)

MSME — Mech. Eng. — 3-5 yrs. exp. Thermal Design and Evaluation (CR)

BSME or equiv. — Mech. Eng. — 3-5 yrs. exp. Environmental Test and Procedures (CR)

BSEE — Elec. Eng. — 4 yrs. exp. Circuit Design and Com. (D)

BSEE — Elec. Eng. — 3-5 yrs. exp. Microwave Systems (D)

BSEE — Elec. Eng. — 3 yrs. exp. Tropospheric Scatter (D)

BSEE — Elec. Eng. — 2-7 yrs. exp. UHF, Scatter, Microwave Systems Design (D)

DATA

BSEE or higher — Senior Staff Asst. — 8-10 yrs. exp Digital (CR or NB)

MS or PhD — Applied Math — 10 yrs. exp. Business Computing (CR or NB)

BSEE — Elec. Eng. — 5-8 yrs. exp. Digital Data Design (D or NB)

MS Applied Math — Business Programming — ext. exp. (D or NB)

MS Applied Math — Logic Program Designer — 8-10 yrs. exp. (D or NB)

PhD Applied Math — Logic Program Designer — 8-10 yrs. exp. (D or NB)

BSEE or higher — Logic Designer — (NB)

BSEE or higher — Peripheral Equip. Designer — (NB)

GENERAL

BSEE or higher — Resident Eng. — 3-5 yrs. exp. Communications (CR)

BSEE or higher — Senior Staff Asst. — 8-10 yrs. exp. TV Theory (CR)

BSEE — Test. Eng. — 3-5 yrs. exp. Communication Design, Testing (CR)

BSEE desirable — Logistics Eng. — 2-5 yrs. exp. Space Program Logistics (CR)

BSEE or higher — R&D Eng. — 1-5 yrs. exp. Antenna Systems (D)

BSEE — Elec. Eng. — 1-5 yrs. exp. Design Review and Prediction (D)

BSEE — Project Test Eng. — 1-5 yrs. exp. Quality Assurance (D)

BSEE — Telephone Eng. — 4-7 yrs. exp. Central Office (D)

ME or IE — Staff Eng. — 2 yrs. exp. in MTM (CR, D or NB)

MS or PhD — Solid State Physics — 3 yrs. exp. Thin Film Dev. (D)

BSIE — Prod. Methods — 1-4 yrs. exp. (CR)

BSEE or higher — Comp. Designer — Exp. in Network Theory (NB)

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On listings marked (CR), send resume to L. R NUSS, COLLINS RADIO COMPANY, CEDAR RAPIDS, IOWA

On listings marked (D), send resume to C P. NELSON, COLLINS RADIO COMPANY, DALLAS, TEXAS

On listings marked (NB), send resume to E D. MONTANO, COLLINS RADIO COMPANY, NEWPORT BEACH, CALIFORNIA

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Our facilities are located in Silver Spring, Maryland, a residential suburb of Washington, D. C., affording you a choice of country, suburban or city living. Public schools are excellent, and five nearby universities offer graduate courses. The cultural pleasures of the Nation's Capital are just minutes away, and the countryside provides every opportunity for sports, from mountain climbing to boating and fishing on the Chesapeake Bay.

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IRE People

(Continued from page 114A)

presently Secretary for the Philadelphia Chapter Professional Group on Space Electronics and Telemetry.

❖

C. M. Hathaway

Claude M. Hathaway (SM'59) until his retirement five years ago President of Denver's Hathaway Instrument Company, announced formation of the new Western Electrodynamics Company in Colorado Springs, Colo.

Mr. Hathaway retired in 1955 to take over a working ranch in Whitewater, Colo., and there four years later built a complete engineering laboratory amid the barns and haystacks of his Western Slope property. Highly interested in measurement and control problems, he spent his time on pure research, producing new types of instruments, improvements on existing varieties, and came up with startling new discoveries. Untroubled with deadlines or production schedules, he proved to himself complete reliability of a broad new line of technical products.

Now a new corporation, Western Electrodynamics, has been formed for precision production of measuring and testing equipment for the public utility industry, transportation industry, and laboratory market.

He was graduated in 1928 from the University of Colorado with a Master's degree. He taught in the Electric Engineering Department for several years. He transferred to General Electric Company at Schenectady, N. Y., first as a project engineer, later as a consulting engineer. By 1935 his developmental efforts won him the Coffin Award, GE's formal recognition of outstanding ability and service to industry.

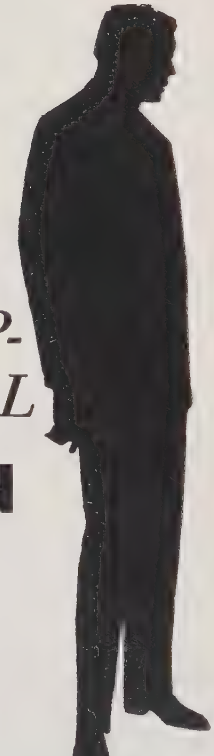
Returning to Colorado in 1939, Mr. Hathaway set up his own consulting engineering office. From this, he developed his Hathaway Engineering Company, pioneering new instruments and control devices for the power industry, aviation, research labs, schools, colleges, hospitals, manufacturers and the military services. In 1955 he sold his interests and retired to cattle ranching.

He is a member of the American Institute of Electric Engineers and the Instrument Society of America. He will personally direct the research and development of the company.

❖

Dr. Benjamin Kazan (A'40–SM'55) has joined the staff of Electro-Optical Systems, Inc., as Chief Scientist of the Solid State

(Continued on page 118A)



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And, the staff keeps channels of communication open between the practitioners of fundamental science and the engineers who provide practical application of new ideas; basic research groups work alongside engineering and development groups.

The Electronics Division at Armour is initiating new analytical and hardware studies in such varied areas as bionics, systems analysis, millimeter waves, power conversion, automata, artificial simulation, VLF, solid state microwave components, computer elements, advanced magnetic recording techniques, microelectronics and medical electronics.

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EE's or Physicists with some experience preferred in one of the following areas: radar, antennas, circuit development, microwaves, radio interference, analysis, guidance and control, propagation, communications, signal processing, semiconductor devices, measurement techniques, computer systems, reliability analysis, component development.

Candidates for these positions should send resume to Mr. Ron C. Seipp, Armour Research Foundation, 10 West 35th Street, Chicago 16, Illinois.

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In recent years, the vastly increased power, sensitivity and amount of new electronic equipment have created a radio frequency interference crisis now being met by an extensive compatibility program. Armour Research Foundation has been given the responsibility for the technical supervision of the DOD's Electromagnetic Compatibility Analysis Center in Annapolis.

Positions are immediately available for

SYSTEMS PROGRAMMERS, OPERATIONS ANALYSTS AND ENGINEERING MATHEMATICIANS/ STATISTICIANS to work in the design of generalized input-output packages, debugging routines, large data files and retrieval systems, developing models of military systems for computer simulation. These positions require a BS degree with experience in programming for large-scale digital computers, operations research, statistical analysis or application of digital computers to systems analysis.

There are openings also for

SYSTEMS ANALYSIS ENGINEERS requiring BS degree, with some experience desirable in radar and communications systems analysis, electronic system measurement techniques, spectrum signature measurement, signal environment analysis or microwaves, antennas and propagation.

Applicants for these positions should address resumes to Mr. S. M. Ream, Armour Research Foundation, USNEES, Annapolis, Maryland.

RADAR SYSTEM DEVELOPMENT— SILVER SPRING, MARYLAND

Another of the Armour Research Foundation's current projects requires the formation of a research team in Silver Spring for the development and evaluation of an advanced radar system having search, track and track-while-scan modes of operation. Assignments here will provide an opportunity to work on an entire weapon system, as well as to grow professionally in areas of development and analysis.

These positions require an EE degree with a minimum of 2 years experience in circuit design, radar development or system development and evaluation. Inquiries should be addressed to Mr. W. A. Massey, P.O. Box #453, Silver Spring, Maryland.

All positions with Armour provide an opportunity to join one of the leading independent not-for-profit research organizations in the country, which undertakes between 600 and 800 projects annually, for approximately 300 companies and 35 government agencies. Attractive salaries, tuition-free graduate study and unusually liberal vacations are among the additional advantages. Inquire about YOUR career with Armour now!

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OUR NEW DIRECTOR OF ENGINEERING should be of Ph.D. level in Electrical Engineering or Physics and must have high technical competence and broad industrial experience as a basis for a productive cooperation with managers and top technical personnel of divisions marketing a wide range of products such as power and special purpose tubes, ferrites, precision resistors, precision timing devices, electromechanical relays, small electric motors, analytical instrumentation and others.

He will supervise a group of engineers who will work closely with outstanding scientists in our Laboratories to put ideas and inventions arising from our research program into a form exploitable by existing or newly created operating divisions.

He must have the experience based on solid accomplishments which will enable him to formulate, acquire and lead development programs under sponsorship of government agencies. He will have the initiative to develop an engineering group with the technical resources required for a substantial and growing industrial organization involved in complex and changing technologies.

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IRE People

(Continued from page 116A)

B. KAZAN

Division. In this position he will be responsible for solid-state research and development programs in thin film techniques and light-imaging and amplifying devices.

Prior to joining Electro-Optical Systems, Dr. Kazan was Head of the Solid-State Display Group of the Hughes Research Laboratories. There he was concerned with research in thin films, image amplification and electrical scanning and switching. Before his association with Hughes, he was a member of the technical staff of RCA Laboratories.

Dr. Kazan received his Ph.D. degree in physics from Technische Hochschule, Munich, his M.A. degree in physics from Columbia University, and his B.S. degree in physics from California Institute of Technology.

He received first prize in the 1957 annual meeting of the American Roentgen Ray Society for demonstrating the medical possibilities of a new amplifying fluoroscope screen. In 1958 he received the Coolidge Award from the General Electric Company for a paper stressing the industrial possibilities of the panel X-ray amplifier.

Dr. Kazan has had thirteen technical papers published in various scientific journals and is co-author of a book entitled, "Storage Tubes." He holds over forty patents in areas of traveling-wave tubes, storage tubes, image intensification, photoconductivity, and other fields.

He is a member of Sigma Xi, Tau Beta Pi, and the American Physical Society.

❖

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Alessio, S. A., Chicago, Ill.
Arbuckle, W. L., Orlando, Fla.
Batson, D. D., Granada Hills, Calif.
Cadwell, E. B., Jr., North Syracuse, N. Y.
Carp, G., Syracuse, N. Y.
Chandler, R. D., Jr., Westfield, N. J.
Chatten, J. B., Philadelphia, Pa.
Clark, M. M., Syracuse, N. Y.
Cook, C. L., Syracuse, N. Y.
Cook, W. E., Highland, Calif.
Crane, R. L., Wantagh, L. I., N. Y.
Dean, J. C., State College, Pa.
Dilson, J., New York, N. Y.
Dodson, G. C., Jr., Schenectady, N. Y.
Doxey, W. L., West Long Branch, N. J.
Ellis, C. R., North Syracuse, N. Y.
Ellison, B., Midland Park, N. J.
Feit, L., Fair Lawn, N. J.
Fleischer, A. A., Goleta, Calif.
Gallagher, D. C., Cedar Rapids, Iowa
Gilleo, M. A., Palo Alto, Calif.
Grannemann, W. W., Albuquerque, N. M.
Grubbs, C. L., Fort Worth, Tex.
Hackert, W., Jr., St. Petersburg, Fla.
Holbrook, R. A., Atlanta, Ga.
Houghton, T. F., Franklin Lakes, N. J.
Huhndorff, E. P., Houston, Tex.
Jackson, A. S., Ventnor, N. J.
Johnson, R. A., Winnipeg, Man., Canada
Jones, W. H., North Syracuse, N. Y.
Kakizaki, K., Fujisawa-shi, Japan
Kirchner, C. W., Lynbrook, N. Y.
Koblick, S. N., North White Plains, N. Y.
Koll, A. J., Jr., Alexandria, Va.
Kovacs, F. M., DeWitt, N. Y.
Leemon, W., Cleveland, Ohio
Lipsky, S. E., Jericho, L. I., N. Y.
Love, S. F., Kitchener, Ont., Canada
Malech, R. G., Plainview, L. I., N. Y.
McDonough, V. T., Verona, N. J.
Mehr, M. H., Norwalk, Conn.
Mertens, L. E., Moorestown, N. J.
Nelson, V. R., Sioux Falls, S. D.
Nichols, B. B., Northridge, Calif.
Pearlman, L. S., Bethel, Conn.
Phillips, F. S., Houston, Tex.
Quick, G. R., Silver Spring, Md.
Richter, J. G., Yonkers, N. Y.
Rubenstein, A. H., Evanston, Ill.
Schuhlein, C. M., Westbury, L. I., N. Y.
Sferrazza, P. J., Melville, L. I., N. Y.
Sletten, C. J., Acton, Mass.

(Continued on page 120A)

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Will develop and design Solid State Hi Voltage power supplies to 30 KV. B.S. in E.E. or equivalent. Experience with power supplies, magnetic amplifiers and transistor circuitry helpful.

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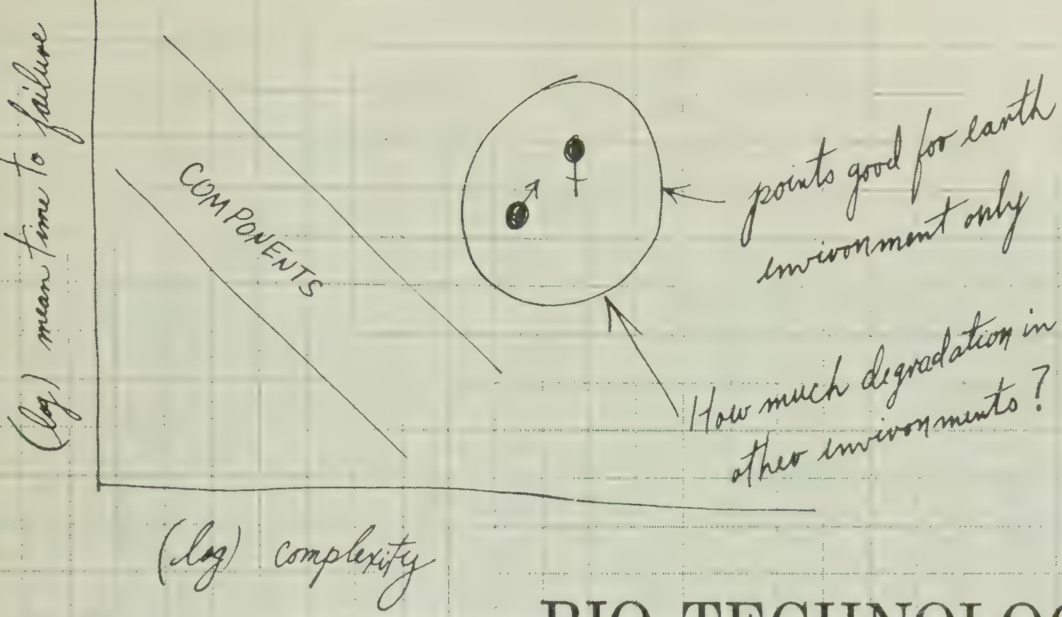
Of interest to engineers and scientists


(log) mean time to failure
COMPONENTS
♂ ♀
points good for earth environment only
How much degradation in other environments?
(log) complexity

BIO-TECHNOLOGY

...one of more than 500 R&D programs under way at Douglas

This Douglas program is studying areas related to man-machine and biological systems as:

- Psycho-physiological monitoring techniques for determining biological stability in normal and exotic ecological systems;
- Cybernetic and bionic principles for application to personnel subsystem support;
- Techniques for producing artificial environments and evaluating their biological effects;
- Learning and teaching machines, remote handling systems, and display and control techniques to support space operations.

Bio-technological devices will be constructed related to experimentation in the above fields. A considerable amount of work has already been accomplished on ecological problems associated with advanced space systems.

Of career interest to engineers and scientists

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(Continued from page 118A)

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(Continued on page 122A)

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PART I of the new Dictionary is compiled from 37 IRE Standards on electronics terms, organized and published by The Institute of Radio Engineers over an 18 year period. Each definition cites the Standard from which it was taken; where a term is used in more than one field, and has more than one meaning, each is listed under a separate entry.

PART II of this 225 page volume is a Dictionary of Symbols, made up of five IRE Standards: Letter Symbols for Electron Tubes; Letter Symbols for Semiconductor Devices; Graphical and Letter Symbols for Feedback Control Systems; Graphical Systems for Semiconductor Devices; and Graphical Symbols for Electrical Diagrams. A four-page index to graphical symbols is included.

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(Continued from page 126A)

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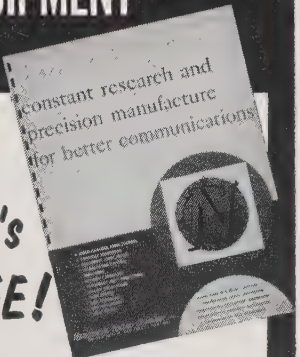

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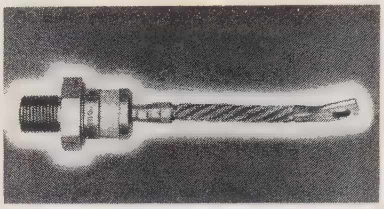
NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 62A)

Silicon Rectifiers

High-power silicon rectifier line with maximum peak reverse voltage ratings to 1000 volts at 240 amperes is available from the **Westinghouse Electric Corp.**, Semiconductor Div., Youngwood, Pa.



The high-power silicon rectifier line (JEDEC registration 1N3171A to 1N3174A) is suitable for high-voltage, high-current applications including electrochemical refining, plating, elevators, cranes, railway traction, and power supplies.

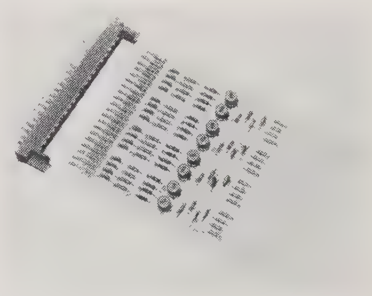
This extension of the high-power rectifier line, from 600 volts to 1000 volts, features an alloyed junction, ceramic insulation to provide greater creepage distances between anode and cathode, metal-to-ceramic seal with welded metal joints for lifetime hermetic seal, and hard solder construction which eliminates thermal fatigue problems.

The rectifier line is available from stock. The devices can also be supplied in assemblies with heat radiating plates.

For further information write to the firm.

Digital Logic Cards

Continuing its policy of product diversification, **Hallamore Electronics Div., The Siegler Corp.**, 714 N. Brookhurst St., Anaheim, Calif., has just introduced a new line of Digital Logic Cards. Typical of the new line is the Model 0500 Universal Flip-Flop Card, which can be used for Binary, Octal, BCD or ring counters, shift registers and storage registers.

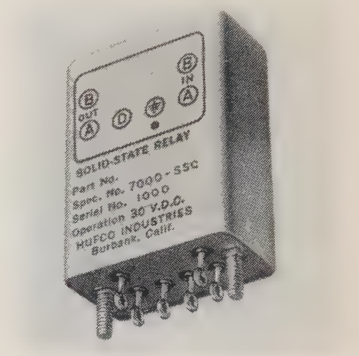


Features of the Model 0500 include set reset, two trigger, and two trigger inhibit inputs on each flip-flop. Systems using the 0500 card require only one type of spare card; low current requirements mean less heat and power. Conservatively rated for 250 kc operation, the card can be supplied for different power-supply voltages. The 0500 card fits Hallamore or Elco card file, and Elco Varicon connectors. Taper tabs permit rapid system redesign. Model 0500 is offered on a 60-day delivery with prices on request.

Model 0570 Universal Emitter-Follower/Inverter Card, and Model 0572 Universal Gate Card are available as companion units to the 0500 Logic Card.

Solid State AC Latching Relay

Hufco Industries, 2815 W. Olive Ave., Burbank, Calif., announces production of a completely solid state ac latching relay. Unit has no mechanical moving parts whatever, and hence provides exceptional reliability. Size is 11/16″×1 9/32″×1.875″ high.



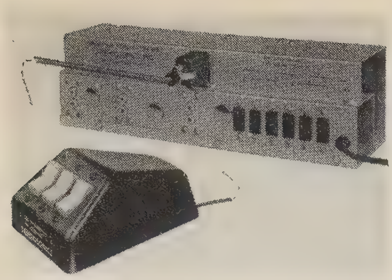
An SPST relay, with a contact rating of 1 ampere, unit operates on an input voltage of 10 to 30 vdc. Contact voltage frequency range: from 300 cps to 30 kc—broad range for a static relay.

Pickup time is 1 ms for relay latching, and dropout time is 2 ms after removal of contact voltage. Unit withstands temperatures from −55 to +100°C, with special models to +125°C. Weight is less than 2 oz. Multipole ac or dc types are also available.

Availability: 3 to 4 weeks. Literature on Model SSA-04 sent on request.

Remote Control

The universal remote control is a new development in the audio and electronics fields from **Stereosonics, Inc.,** Box 4205, Long Island City 4, N. Y. It is designed to permit remote operation of any component or console system over distances of up to 800 feet. Models RM-2 and RM-3 permit continuous control of both volume and tuning as well as turning on and off ac power to components or appliances. It connects in minutes electronically or mechanically to any system. It may be connected electronically via any pair of input and output RCA component jacks (i.e. Tape input and Tape output), etc., or mechanically via the accessory FC-1 flexible shaft cable to any ¼ inch tuning or potentiometer shaft. Any number of remote switch control centers may be used with a single slave motor chassis. No audio signals pass through cables and no distortion, noise or loss of frequency response is introduced.

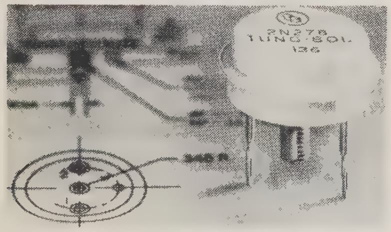


Remote control is available in both two and three channel models. The two channel Model (RM-s), sells for $75.00 and comes completely assembled with a two motor slave chassis, a remote switch control box, forty feet of cable, and four audio connecting cables. The RM-3 is a three channel model and sells for $95.00. Extension cables, additional control centers, and flexible shaft cables are available as accessory items.

For further information contact the firm.

Germanium Transistors

An expanded line of 15-ampere germanium transistors designed especially for high power industrial and military applications has been announced by **Tung-Sol Electric, Inc.,** 1 Summer Ave., Newark 4, N. J. Typical circuit uses of the transistors include power amplifiers, dc to dc converters, dc to ac inverters, regulated power supplies, motor controls, servo amplifiers and relay drivers. The line consists of 18 different type numbers including a JAN approved Type 2N174 and a USA Type 2N1358.



Maximum collector dissipation is 170 watts. The derating factor is 0.5°C/W and maximum junction temperature is +110°C. Vcbo ratings vary from −40 v to −100 v.

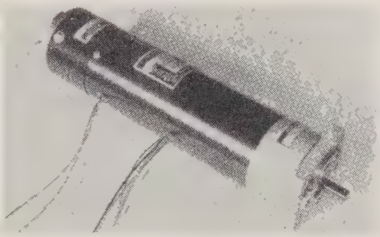
The transistors are available in a standard TO-36 case style which has a cold-weld copper-to-copper hermetic seal. Bonded glass-to-metal terminals insulate the emitter and base connections from the case. The collector is connected internally to the transistor mounting base. Available from stock.

All of these types are available as standard stock items from Tung-Sol distributors.

Universal Radiometer

Allied Radiation Equipment Co., 250 Fulton Ave., Hempstead, N. Y., has developed a new radiometer. This instrument may be used with all standard photomultipliers operating in the 1000 volt range. The radiometer has a regulated supply such that it is insensitive to variations either line or load. The unit may be turned off for a period of time and then reset to its original level so as to provide the same sensitivity from the photomultiplier. Light levels in the order of 1–2 microlumens may be measured accurately. The instrument may be used as either absolute or a relative indicator. The over-all size is less than 8″ high and a flexible cable carrying the proper photomultiplier socket is attached in the rear. A pair of binding posts on the front panel may be used to select an anode load for the photomultiplier chosen so as to get a voltage output proportional to light. The use of both a coarse and fine control guarantees smoothness and insensitivity of this adjustment. This equipment is available now. For price and delivery contact the firm.

400 cps Synchronous FHP Motor



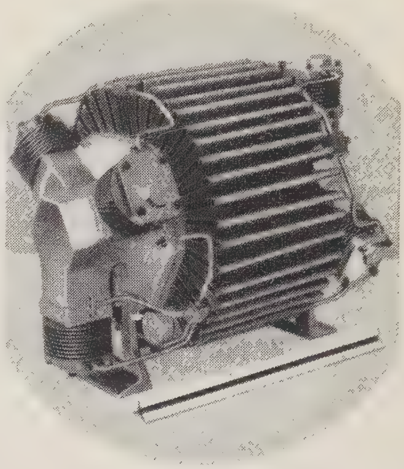
Globe Industries, Inc., 1784 Stanley Ave., Dayton 4, Ohio, has developed a new version of their FC 1.675 inches OD motor which provides for 4, 6 or 8 pole operation depending on coils energized, resulting in outputs of 12,000, 8000 or 6000 rpm at 1 inch-ounce torque. Input power requirements are 30, 20 and 18 watts, respectively, 3 phase (6 pole operation uses 2 legs and neutral), 115 volts ac, 400 cps. Unit can be operated as a single phase capacitor-run motor but at reduced torque rating. The rotor is a hysteresis type operating synchronously within the torque capacity of the motor. The motor pictured includes a dc brake and planetary gear reducer, standard Globe components. The motor can be supplied with a variety of windings for differing input specifications. Further information is available from the firm.

300–500 Volt dc Supply

Kilovolt Corp., 238 High St., Hackensack, N. J., announces an addition to its line of regulated high voltage power supplies. The new unit, Model KVR5-1000, is

(Continued on page 130A)

closed-cycle
Cryogenic Cooling
...simplicity
...reliability



Non-contaminating compressors are one of Air Products many contributions to advance the "state of the art" in cryogenic hardware. These machines offer an order-of-magnitude reduction in compressor size and weight.

At temperatures approaching absolute zero, oil and all constituents of air freeze, causing refrigerator malfunctions. To overcome this problem, Air Products non-contaminating compressors incorporate:

- **oil-free running gear**
- **carbon-filled fluorocarbon piston rings** which are self-lubricating
- **hermetically sealed compressor-motor package** which prevents contaminants from entering the system and refrigerant from escaping

Two- and six-cylinder versions of these compressors are in use with Air Products closed-cycle infrared and maser cooling systems.

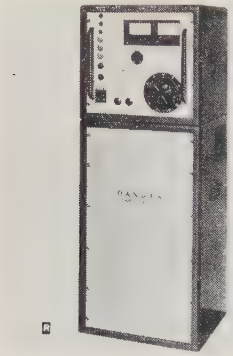
ADVANCED PRODUCTS DEPARTMENT
DEFENSE AND SPACE DIVISION

Air Products and Chemicals INC.
Allentown, Pennsylvania

▶ Air Products manufactures a complete line of cryogenic electronic coolers.

(Continued from page 129A)

a high voltage power supply, highly regulated against input line variations or changes in load. Output control is continuously variable from 300–5000 volts dc at 1 ampere rated current with regulation better than ±0.1% against a line change of ±10% and a full change in load. Ripple is held to less than 0.02% R.M.S.

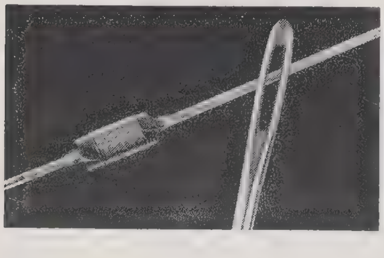


Model KVR5–1000 is housed in a single cabinet measuring 22″ wide × 18″ deep × 57″ high and weighs approximately 400 lbs. Input is 230 volts ac, 60 cps 1 ϕ with maximum input current rated at approximately 50 amperes. The power supply features reversible polarity, over-current control from 0.17 to 1.05 amperes accurate single range voltage and current meters.

As in other Kilovolt Corp. power supplies, all components are conservatively rated, meters are electronically protected against overloads and functional pilot lights are employed. The unit has been engineered to provide maximum protection to the equipment, the load and the operator. For technical bulletin and price information write to the firm.

Subminiature R.F. Chokes

Delta Coils, Inc., 1128 Madison Ave., Paterson 3, N. J., has announced the latest addition to its catalog, a new line of subminiature iron core RF chokes. The new line is known as 1900 RF Miniachokes. It includes 39 coils covering a complete range of useful inductances—1.0 μh to 10.0 mh. Engineered for use in network and filter design, delay lines, transmitter and receiver equipment, portable TV receivers and computer applications, they are useful where small size and light weight are important.



All are ruggedly constructed for dependable uniform performance and are impregnated to provide moisture and fungus resistance.

The coils have a 50 milliampere maximum dc current rating.

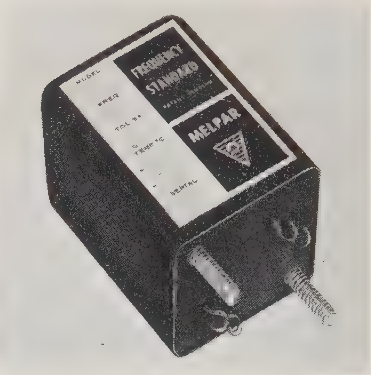
Miniachokes feature high permeability, high Q, easily formed tarnish-free axial leads. They can be furnished epoxy encapsulated to conform to Grade 1, Class B of MIL-C-15305B.

The new line was available April 1, and will be stocked for off-the-shelf delivery.

Prices range from 32 to 52 cents in 100 piece lots. Less than 100 piece prices and large quantity prices will be furnished on request.

Frequency Standard

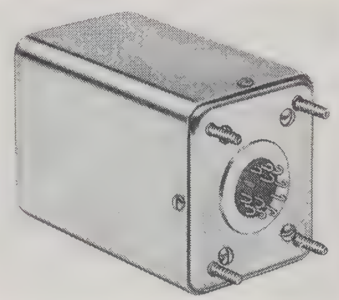
A new tuning fork frequency standard, which provides crystal-type accuracy at audio frequencies over a wide range of input voltages, has been announced by **Melpar, Inc.,** 3000 Arlington Blvd., Falls Church, Va. With accuracies of ±0.01% over wide temperature ranges and severe environmental conditions, the Model 310 can be used in applications where input power ranges from 22 volts to 32 volts. Other ranges are available.



The Model 310 provides simultaneous sine wave and square wave outputs.

The new frequency standard consists of a precision tuning fork and transistorized oscillator, both packaged in one small hermetically sealed case (MIL-T-27 Type AH) 1 17/64″×1 17/64″×1 3/4″. The device weighs less than 2.9 ounces.

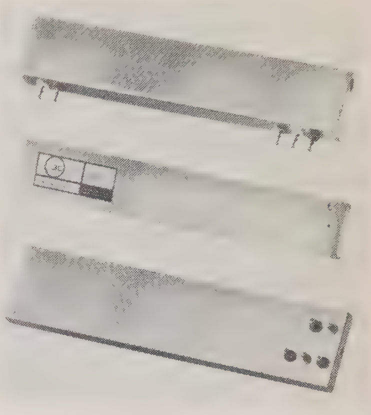
Transistor Oscillator



Monitor Products Co., Inc., 815 Fremont Ave., South Pasadena, Calif., announces its HP Series crystal-controlled transistor oscillator. The unit is available in either silicon or germanium. Standard frequencies are from 60–1000 cps with frequency tolerances to 1 part in 10^6. Output waveforms are sine wave 1 volt *p-p* (Germanium) and 2 volts *p-p* (Silicon) or square wave. Prices are from $300.00 to $600.00 in small quantities depending on specifications. For further information contact John Blasier at the firm.

Magnetostrictive Delay Line

Computer Control Co., 983 Concord St., Framingham, Mass., announces the recent development of the Model S33 Soniline, a compact ultra-reliable magnetostrictive delay line for direct use in high-speed digital computers (one word buffers, address registers, etc.); underwater sound detection systems (deltics, time compressors); ground support equipment (correlation, timing); and other applications where economical low-capacity data storage is required.



The S33 has a continuously variable delay adjustment with infinite resolution over the range of 4 to 14 μsec, and operates at frequencies of 1 to 4 mc. Maximum storage capacity is 56 bits at a 4 mc rate. Higher capacities can be obtained by connecting several units in series, via interstage drivers. The temperature coefficient of delay is ±5 nanoseconds from 0 to 80°C, and the nominal signal-to-noise ratio is 10:1. Typical insertion loss is 55 db.

The entire unit weighs approximately 2 ounces, is housed in a stainless-steel case measuring 5″ long × $1\frac{1}{8}''$ wide × $\frac{1}{2}''$ high, and is ideally suited for stud mounting on printed circuit boards. Input and output connections are made by means of $\frac{1}{4}$ inch turret lugs.

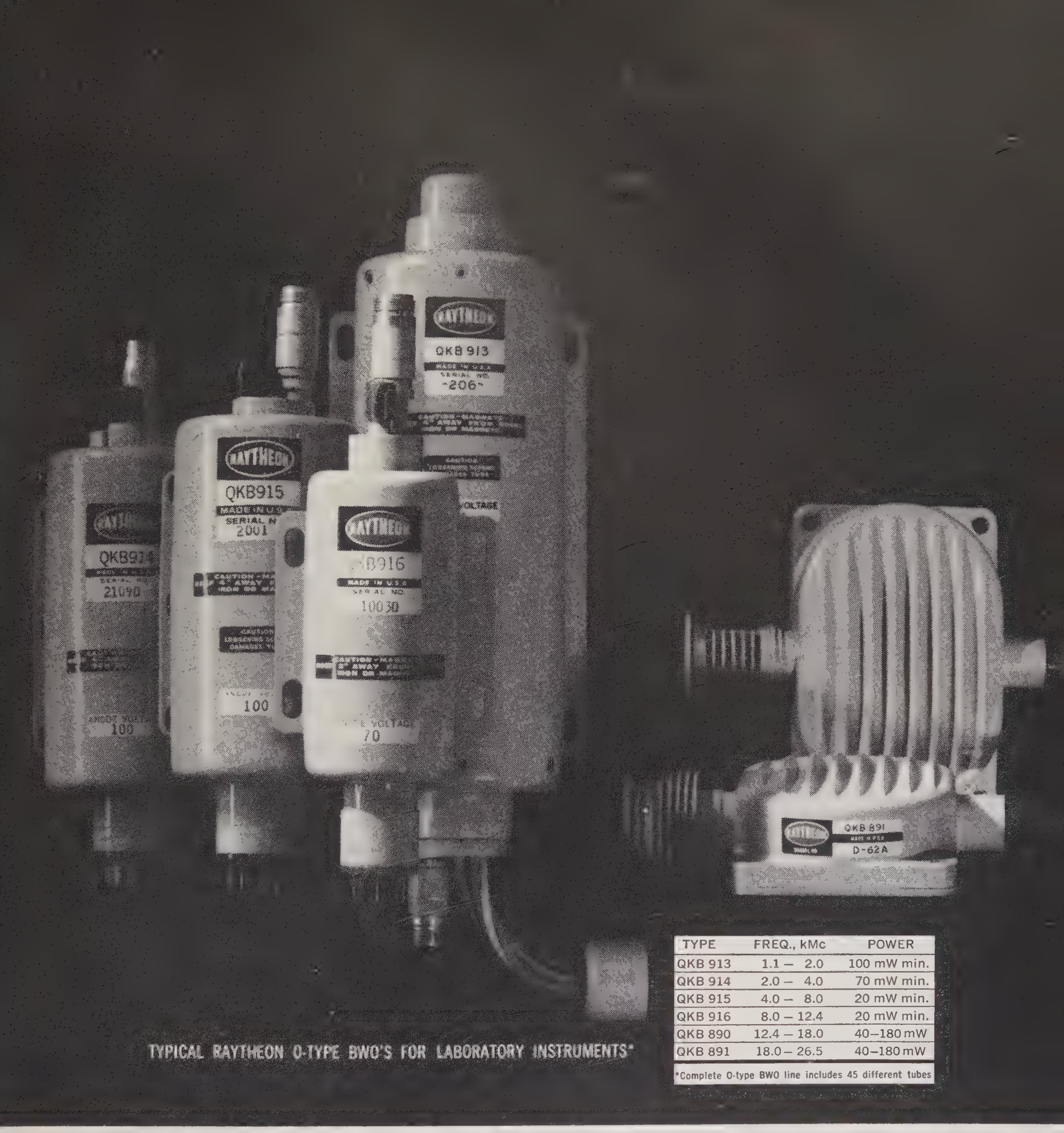
Delay line taps and compatible input-output circuitry are available on special order. Delivery: 30 days, or as quoted. Price: $70 to $150, depending on quantity.

Air Frame Relay

Struthers-Dunn, Inc., Pitman, N. J. offers a series of three balanced armature relays designed primarily for air frame use to MIL-R-6106C specifications. Known as the Dunco FC-400 Series, the relays feature a dual-coil, balanced armature design that combines low operating power requirements with the ability to withstand 10G vibration to 1500 cycles and 25G shock for 6/9 millisecond.

Each unit is hermetically sealed. Bi-

(Continued on page 132A)


RAYTHEON
QKB 913
MADE IN U.S.A.
SERIAL NO.
206
RAYTHEON
QKB915
MADE IN U.S.A.
SERIAL NO.
2001
100
RAYTHEON
QKB914
21090
ANODE VOLTAGE
100
RAYTHEON
QKB916
MADE IN U.S.A.
SERIAL NO.
10030
VOLTAGE
70
QKB 891
MADE IN U.S.A.
D-62A

TYPICAL RAYTHEON O-TYPE BWO'S FOR LABORATORY INSTRUMENTS*

TYPE	FREQ., kMc	POWER
QKB 913	1.1 – 2.0	100 mW min.
QKB 914	2.0 – 4.0	70 mW min.
QKB 915	4.0 – 8.0	20 mW min.
QKB 916	8.0 – 12.4	20 mW min.
QKB 890	12.4 – 18.0	40–180 mW
QKB 891	18.0 – 26.5	40–180 mW

*Complete O-type BWO line includes 45 different tubes

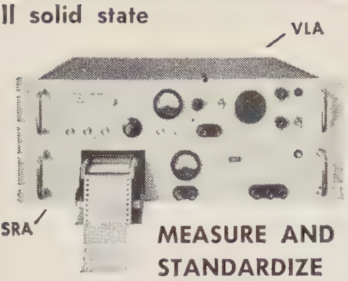
Why 3 out of 5 BWO's in new microwave signal generators are Raytheon

Certainly it's more convenient to select from Raytheon's 45 different BWO's. But most needs are met with six tubes covering 1 to 26.5 kMc (above). They're unusually compact and incorporate grids for low-voltage pulse and amplitude modulation or the application of AGC. Write for more reasons in technical data. Raytheon Co. □ Microwave and Power Tube Div., Waltham 54, Mass.

RAYTHEON

STANDARD FREQUENCY RECEIVERS

all solid state

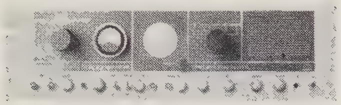


MEASURE AND STANDARDIZE FREQUENCIES TO ONE PART IN 10 BILLION!

MODEL VLA Receiver Phase Comparator and MODEL SRA Servo Phase Shifter

make an automatic system for standardizing local frequencies to VLF standard frequency broadcasts. Graphic records of corrections made to local oscillator signals. Uses inexpensive oscillators. Each unit 3½" standard rack panel.

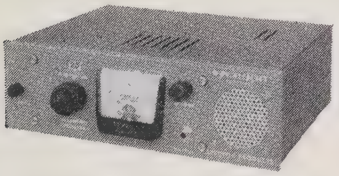
MODEL VLA $1490 MODEL SRA $1485



MODEL WWVC COMPARATOR

Highly sensitive (1 μv) crystal controlled receiver for utilizing WWV and WWVH transmissions in precision audio and radio frequency work and time interval measurements. 2" oscilloscope, 3" speaker.

5¼" x 19" x 9½" rack mount $690
Cabinet model $750



MODEL SR7-H WWV RECEIVER

Dual conversion type. S meter, phone jack and speaker. Noise limiter, antenna trimmer, and provision for oscilloscope or headphones.

3½" x 19" x 8½" rack mount or 3½" x 12" x 8½" bench model $285

MODEL WVTR RECEIVER

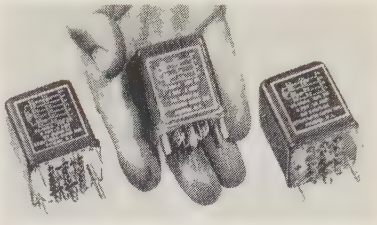
All transistorized for utilizing WWV and WWVH broadcasts. Frequencies to 25 mc crystal controlled. Rack 3½"x19"x5½".

Battery power $560 AC power supply $590
Portable WWVT (9"x12"x5") available $590

SPECIFIC PRODUCTS
P.O. BOX 425 21051 COSTANSO ST.
WOODLAND HILLS, CALIF.
DIAMOND 0-3131 AREA CODE: 213
Prices & specifications subject to change

(Continued from page 130A)

furcated contacts and the use of nongassing materials enhance contact reliability and permit use over a temperature range from −70°C to 120°C.



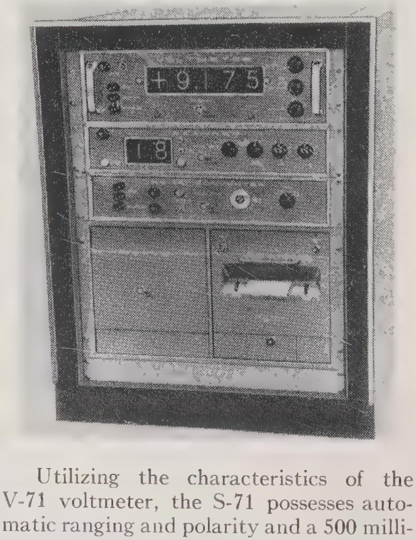
Basic styles include the 10 ampere, 4P-DT, Type FC-400; the 5 ampere, 4P-DT, Type FC-404; and the 5 ampere, 6 P-DT, Type FC-406. All three types are designed for Class B8 service, but are likewise applicable to A5 and A8. Modifications of the basic design for MIL-R-25018 and MIL-R-5757D requirements also can be furnished.

Dunco FC-400 Series relays are available with 28 volt dc operating coils and with self-contained rectifiers for operation on 115 volts ac. Solder hook terminals and 4 stud mounting types are standard, but other available mounting styles include bracket, plug-in, solder lead, screw terminal and so forth.

Prices of FC-400 Series relays start at $24.00 for small quantities. Deliveries of standard types can be made approximately four weeks after receipt of order.

Instrumentation System Built Around Digital VM

Cubic Corp., San Diego 11, Calif. announces a precision laboratory instrumentation system built around its model V-71 digital voltmeter. Companion instruments in the S-71 system include a scanner and an 11-channel printer.



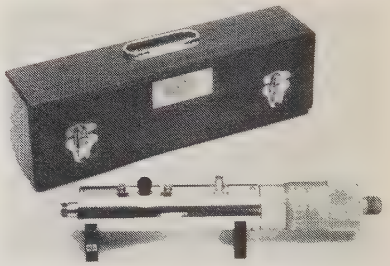
Utilizing the characteristics of the V-71 voltmeter, the S-71 possesses automatic ranging and polarity and a 500 millisecond balance time. The V-71 voltmeter's design features silent reed relays, sealed in glass, and eliminates standard stepping switches and with them the need for periodic maintenance.

The S-71 is applicable to environmental test data recording, modular check-out and production check-out, where recorded data is necessary. System accuracy has been set at 0.01%, plus or minus one digit throughout its entire dc range from 1 millivolt to 999.9 volts. High input impedance allows the system to be standardized directly from standard cells.

The system has the ability to maintain its precision under adverse environmental conditions. The transistor driven reed relays used in the critical switching circuits are impervious to moisture, dust and dirt, require no maintenance, and are ultra-reliable. All contacts are gold-plated. The S-71 is priced at $5270.

Calibrated R-F Voltage Transfer Standard

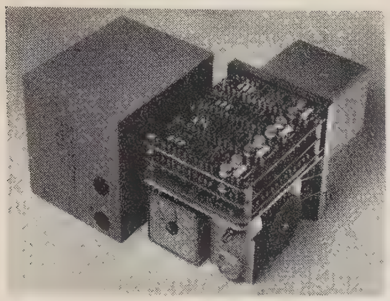
General Microwave Corp., 155 Marine Street, Farmingdale, N. Y., announces the availability of the Model 350 A-T Voltmeter. This instrument is a laboratory reference voltage standard designed primarily to measure voltages and to calibrate voltmeters over a range of from 0 to 500 volts, and in the frequency range from 10 to 1000 megacycles. It is manufactured by General Microwave, based on designs by Myron C. Selby and L. F. Behrent of the National Bureau of Standards, Boulder, Colorado, and is licensed under patents of the United States Government.



Before using, the Model 350 A-T Voltmeter must be calibrated and certified by the National Bureau of Standards. The calibration data provided is in the form of two charts which relate frequency, micrometer setting and voltage. After calibration, it is guaranteed to be accurate to within ±1% for at least one year.

The model 350 consists of an adjustable waveguide-below-cutoff attenuator operating in the TM_{01} mode in combination with a UHF vacuum thermocouple. The calibration stability of the attenuator-thermoelement (A-T) combination is the result of care taken in the choice and fabrication of its component parts and its simplicity of construction. The barrel of the attenuator is carefully machined to a uniform cross section, then gold-plated and honed to the final finish. The exterior of the barrel is nickel-plated. The movable electrode and the thermocouple are mounted on a machined carriage that slides inside the attenuator barrel on two sets of gold-plated finger stock and six nylon pins. A specially designed oversized two inch micrometer drive, calibrated to 0.0001 inch, is employed for maximum resolution of readout. Each model is housed in a felt-lined mahogany storage and carrying case. Price is $1,950.00 and delivery is from stock to 60 days.

Crystal Frequency Standards

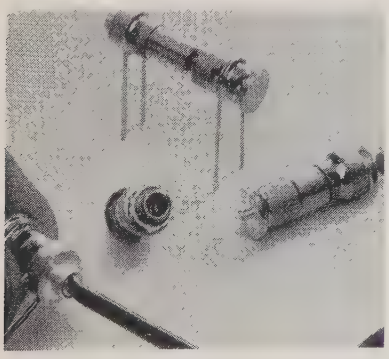


Reeves-Hoffman Div., Dynamics Corp. of America, Cherry St., Carlisle, Pa. has developed the S1115. This 60 cps frequency standard is one of a new line of subaudio and audio crystal-controlled frequency standards, which have frequency stabilities as low as 1 part in 10^7. S1115, for operation on 12.6 volts ac, has a minimum sinusoidal output voltage of 1 volt rms across a quarter-megohm load. Crystal is glass enclosed in a proportional-controlled oven, which maintains a constant, stable temperature. This type of oven eliminates transient noise from the heater circuit, which cannot enter the output. Adjustments are available to compensate for aging of the crystal and other components over the life of the standard.

Similar standards are available for frequencies from 10 to 50 cps, with either square-wave or pulse outputs, and from 50 to 120 cps, with sine, square-wave or pulse outputs.

Hermetically Sealed Miniature Glass Trimmer Capacitors

Hermetically sealed miniature glass trimmer capacitors have been developed by **Corning Electronic Components,** Corning, N. Y., for use in severe environments. Ideal applications are where the trimmer interior must not be subjected to moisture in uses such as potted circuits or airborne, missile and satellite electronic systems.



Fixed cavity tuning with the new sealed Mini-Trimmers is smooth and linear, the Corning Glass Works department said. Change in capacitance is only 0.4 picofarads per turn.

(Continued on page 134A)

IS *YOUR* COMPANY ON THE *OFFENSE* FOR *DEFENSE?*

SIGNAL is your introduction to the men who control government's growing $6.5 billion radio-electronics spending

Never before have our armed forces so badly needed the thinking and products of the electronics industry. Advertising in SIGNAL, the official journal of the *Armed Forces Communications and Electronics Association,* puts you in touch with almost 11,000 of the most successful men in the field—every one a prospect for your defense products!

Share in the defense and the profits! Company membership in the AFCEA, with SIGNAL as your spokesman, puts you in touch with government decision-makers!

SIGNAL serves liaison duty between the armed forces and industry. It informs manufacturers about the latest government projects and military needs, while it lets armed forces buyers know what *you* have to offer to contribute to our armed might. SIGNAL coordinates needs with available products and makes developments possible.

But SIGNAL is more than just a magazine. It's *part of an over-all plan!*

A concerted *offensive* to let the government, which has great faith in industry and the private individual producer, know exactly what's available to launch its far-sighted plans. Part of this offensive is the giant AFCEA National Convention and Exhibit (to be held this year in Washington, D.C., June 12-14) Here, you can *show* what you have to contribute directly to the important buyers. Your sales team meets fellow manufacturers and military purchasers and keeps "on top" of current government needs and market news.

Besides *advertising* in SIGNAL which affords year-round exposure by focusing your firm and products directly on the proper market . . . besides *participation* in the huge AFCEA National Convention and Exhibit . . . the over-all plan of company membership in the AFCEA *gives your firm a highly influential organization's experience and prestige to draw upon.*

As a member, you join some 175 group members who feel the chances of winning million dollar contracts are worth the relatively low investment of time and money. On a local basis, you organize your team (9 of your top men with you as manager and team captain), attend monthly chapter meetings and dinners, meet defense buyers, procurement agents and sub-contractors. Like the other 60 local chapters of the AFCEA, your team gets to know the "right" people.

In effect, company membership in the AFCEA is a "three-barrelled" offensive aimed at putting your company in the "elite" group of government contractors —the group that, for example in 1957, for less than $8,000 (for the full AFCEA plan) made an amazing total of *459.7 million dollars!*

This "three-barrelled" offensive consists of

(1) Concentrated advertising coverage in SIGNAL, the official publication of the AFCEA;

(2) Group membership in the AFCEA, a select organization specializing in all aspects of production and sales in our growing communications and electronics industry; and

(3) Attending AFCEA chapter meetings, dinners and a big annual exposition for publicizing your firm and displaying your products.

If *you're* in the field of communications and electronics . . . and want prestige, contacts and exposure . . . let SIGNAL put your company on the *offense* for *defense!* Call or write for more details—now!

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ARMED FORCES COMMUNICATIONS AND ELECTRONICS ASSOCIATION

BPA

NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 133A)

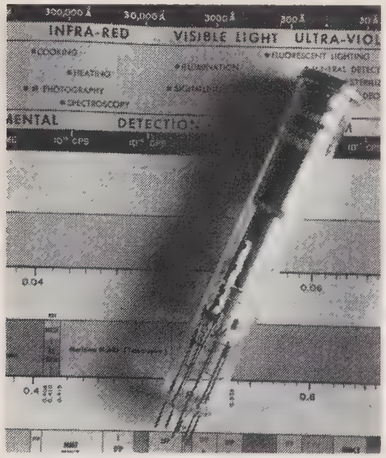
Capacitance ranges of four models, each available with panel mount or printed circuit hardware, are 1-to-4.5, 1-to-8.5, 1-to-12 and 1-to-18 pf.

The trimmers' direct traverse tuning mechanism, enclosed at all positions, includes positive stops at both ends of the tuning stroke and prevents backlash or capacitance reversals. Silver plated hardware and special glass dielectric provide maximum resistance to corrosion, vibration and shock. All models can be tuned with standard screwdrivers.

Operating range is −55 to 125°C, with no derating at 125°C. Q factor at 50 mc is 500. DCVW is 1000 volts, and dielectric strength is 1500. Insulation resistance is 10^6 megohms. Temperature coefficient is ±50, ±75 and ±100, depending on model.

Ultraviolet Slow-Scan Vidicon

A new ultraviolet vidicon camera tube, the WX-4887, is now available from the **Westinghouse Electronic Tube Division,** Box 284, Elmira, N. Y. It may be used in any standard vidicon camera chain but has excellent light integration and storage characteristics for slow scan applications. The ultraviolet response is about 1800 angstroms but can be extended to 1200 angstroms.



The new tube has extremely low dark current and maintains useful image resolution, for storage or frame scan, up to several minutes. This slow-scan feature is significant if the tube is to be used in narrow bandwidth equipment such as that found in space vehicles.

Available with magnetic deflection, the tube can also be supplied with electrostatic deflection. Tubes with either type of deflection can be made with rugged construction.

Measuring 6.25 inches in length, the tube is 1.125 inches in diameter.

For more information write to the firm.

Silicon Epitaxial Mesa Transistor

The development of a new silicon epitaxial mesa transistor packaged in the co-planar configuration has been announced by the **Semiconductor Div., Sylvania Electric Products Inc.,** Woburn, Mass., a subsidiary of General Telephone & Electronics Corp.

Designated the 2N2397, this transistor is within the JEDEC TO-51 outline and is dimensioned at 0.145 inch maximum outside diameter for insertion in a 0.150 inch diameter hole. The geometry of the 2N2397 makes this unit ideally suited for hole-in-board Swiss Cheese packaging techniques. Also, the leads may be omitted to enable leadless "dot" circuit packaging.

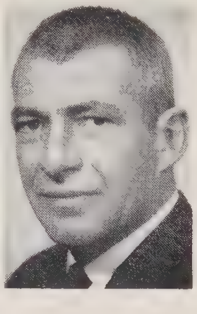
The 2N2397, a forerunner of a complete family of similar units, is designed primarily for high speed switching and high frequency service. The combination of hermetic seal, passivated protected surfaces, rugged epitaxial mesa construction, and the unique microminiature size makes the 2N2397 ideal for new equipment design and easy adaptation to existing designs.

Priced at $20.00 for quantities of 1 to 99 and $15.00 for 100 and up, the 2N2397 is available through Sylvania franchised semiconductor distributors and Sylvania semiconductor sales offices.

Weinschel Appoints Sachs

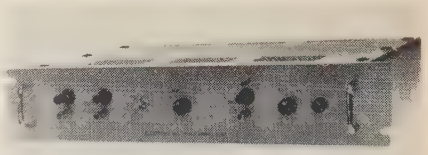
John Wilson Sachs has been named as head of the Physical Chemistry Section of **Weinschel Engineering Co., Inc.,** 10503 Metropolitan Ave., Kensington, Md., manufacturers of precision microwave test equipment.

Prior to associating with Weinschel, Mr. Sachs was a Chemical Engineer with the Naval Ordnance Laboratory for nine years, first as a member of the Evaluation Group in the Chemistry and Corrosion section, Ordnance Surveillance Branch of the Mechanical Evaluation Division, and later with the Pyrotechnics Branch in the Chemical Engineering Division. In this capacity, he was one of three to receive a group meritorious civilian award for the development of a family of drill mines and pyrotechnic signals. His previous association was with Oak Ridge National Laboratory at Oak Ridge, Tennessee.



Computer Multiplier

A fast response electronic analog multiplier has been developed by **Intectron, Inc.,** 2300 Washington St., Newton Lower Falls, Mass., to meet the qualitative performance, versatility, and high speed response time requirements in computer, simulator and control systems as well as for special analytical instruments. Operation is based upon the Quarter Square Principle where $(x+y)^2-(x-y)^2/4=xy$. The device accepts two input voltages, x and y, and produces a single output voltage $xy/20$. It employs direct coupled, low drift chopper stabilized amplifiers and has a solution time of approximately 8 microseconds thus permitting multiplication of signals over a wide spectral range.



For performing correlation, convolution and Fourier analyses of time varying signals, the unit can be easily modified so that the output $xy/20$ is integrated with respect to time. Of significant importance is that by time sharing the model 500A multiplier, a number of multiplication channels can be provided for complex simulation and computational problems. Division operations can be performed by altering interconnections of the basic modules or by using the multiplier in conjunction with an inverse function generator.

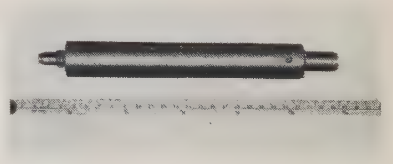
Operating as a modulator, the model 500A permits precise generation of amplitude modulated signals. The unit can provide instantaneous indication of power consumption and may also be used to correct calibration for variations in recording system transducer reference signals.

Of subminiature modular construction, this compact unit uses solid-state diodes and subminiature vacuum tubes combined in six plug-in modules. The design has an exceptional degree of reliability, front panel operation, and includes a switching arrangement for reversing polarity of product signal voltages.

The unit is available for relay rack mounting or as a bench instrument. Power supplied for single or multiple unit operation can be provided. Complete data is available from the firm.

Neutron Generator Tube

The Amperex Type 18600, a hermetically sealed 14 Mev neutron generator tube requiring no external pumping arrangement of any kind, has been announced by **Amperex Electronic Corp.,** Nuclear Products Dept., 230 Duffy Ave., Hicksville, L. I., N. Y. Moderately priced, rugged and exceedingly compact, it is eminently suited for use as a basic laboratory tool wherever a continuous or pulsed source of monoenergetic neutrons is required.



Utilizing the d-t reaction, the type 18600 has a continuous yield of 10^8 neutrons per second with a neutron energy of 14 Mev.

The tube consists of a Penning-type ion source, one-stage acceleration system, target and replenisher, all enclosed in a hermetically sealed tubular glass-and-metal envelope. The envelope is mounted in a cylindrical, oil-filled steel housing, $19\frac{3}{4}''$ long, $2\frac{3}{4}''$ in diameter. It comes supplied with a 12-ft. length of high voltage cable.

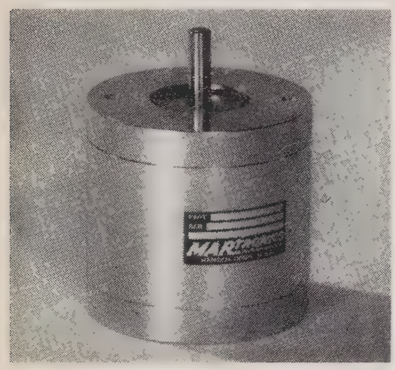
The type 18600 operates at a target voltage of 125 kv and a beam current of 100 microamperes.

The Penning-type ion source requires 2 kv and a maximum current of 3 milliamperes. Pulsed operation is easily attained by pulsing the ion source and yields of 10^{10} neutrons per second for the duration of the pulse can be achieved. The self-contained replenisher system makes it possible to maintain a constant gas pressure within the tube and target, assuring a stable yield over long operating periods.

Further information may be obtained from the firm.

Fractional HP Motors

A new line of three-inch motors, providing an output from one-sixth to one-hundredth horsepower, have been recently developed and are now being produced by **Martronics, Inc.,** 82 Sandford St., Hamden, Conn. Operating at frequencies from 60 to 400 cps and voltages up to 440 volts, these new motors offer the high efficiency needed for advanced systems requirements where low temperature, high torque and quiet operation are specified.



These new compact motors include induction, reluctance-synchronous and hysteresis-synchronous types that provide high torque over wide temperature ranges and meet environmental requirements of military specifications.

In addition to single-wound motors with an input ranging from 1.5 to 10 watts, Martronics is producing bifilar-wound motors for use in such applications as transistorized push-pull power supplies.

It is claimed that life expectancy exceeds 1000 hours under continuous operation, that total indicator readings on shaft run-out do not exceed 0.0001 inch, and that synchronous motors can be provided in matched, counter-rotating pairs which achieve synchronization simultaneously.

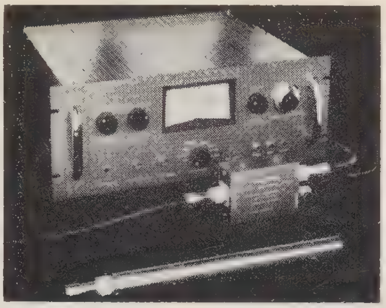
These matched pairs are suitable for applications where control functions, such as those in inertial guidance systems, demand precision timing. Other applications proposed for these new Martronics motors are tension drives, stroboscopic devices, wire and tape recorders and various control operations.

Motors are available with aluminum housings for light weights or with steel housings for RF shielding; and they are also available with special mountings, special shafts and insulation, according to the manufacturer.

For further information, engineers are invited to write W. A. Brink, Sales Manager of the firm.

Neutron Monitor

Radiation Technology, Inc., 715 Miami Circle, N.E., Atlanta, Georgia, has completed development and has available for immediate shipment a new M-600 Neutron Monitoring System.

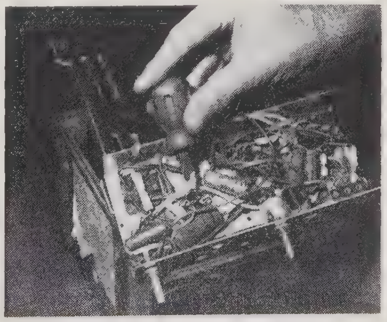


The system consists of the Neutron Monitor Model H-590, a Pre-Amplifier Model H-100, Proportional Counter (BF_3) and interconnecting cables. The system is fully transistorized and incorporates all the features required for neutron monitoring applications. A proportional counter (BF_3) is supplied as standard equipment but it can be used with GM tubes or scintillation detectors. It may also be used in a variety of other nuclear applications as a monitor or as a precision laboratory ratemeter. Uses other than monitoring include measurement of activity of environmental specimens, medical isotope studies, and radioisotope education programs. For monitoring or experimental purposes, the rate meter may be used with BF_3 counters or fast neutron dosimeters for neutron measurements or with GM or scintillation detectors for gamma-ray measurements.

For additional information contact: Nuclear Industries, Inc., 99 W. Hawthorne Ave., Valley Stream, N. Y.

Cold Solder Silver Epoxy Compound

A silver conductive epoxy compound solder that cures in 4 hours at room temperature has been developed by **Anchor Alloys Inc.,** 968 Meeker Ave., Brooklyn 22, N. Y.



(Continued on page 136A)

for highest quality

REGULATED DC POWER SUPPLIES

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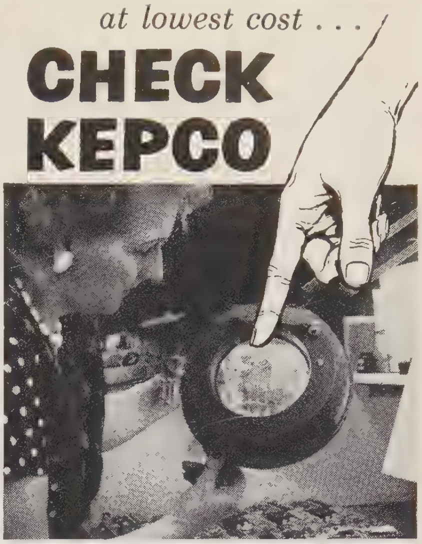
CHECK KEPCO



Kepco's reputation for outstanding product performance is achieved by rigid QUALITY CONTROL—100% inspection and testing is an integral phase of the manufacturing process.

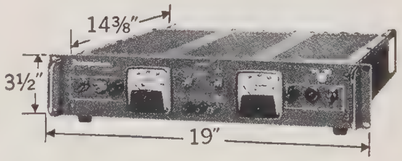
HB REGULATED DC SUPPLY KEPCO'S

PACK MORE VALUE...

RELIABLE:
Unique design uses transistorized reference and amplification circuitry for optimum regulation, stability and long life; plus tube series pass elements for reliable high-voltage operation.

EXCEPTIONAL PERFORMANCE:
Conservative specifications give a true picture of operating characteristics.

ECONOMICAL:
Long trouble-free operating life eliminates costly down time.



PRICE	0.1% MODELS	DC OUTPUT RANGE		0.01% MODELS	PRICE
		VOLTS	MA		
$295.00	HB 2M	0-325	0-200	HB 20M	$495.00
$350.00	HB 4M	0-325	0-400	HB 40M	$550.00
$395.00	HB 6M	0-325	0-600	HB 60M	$595.00
$415.00	HB 8M	0-325	0-800	HB 80M	$615.00

- Full Range Regulation: 0-70-130-195-255-325v dc/800ma
- Programming over full voltage range
- Remote output voltage control
- Constant current operation
- No voltage overshoot

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These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 135A)

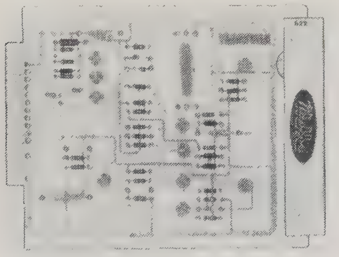
Bonding firmly to any metallic or nonmetallic surface with a strength superior to the usual metal solders, and a shear strength of 3200 psi, Shurbond 102 has a volume resistivity approaching that of metals—0.01 to 0.0005 ohm/centimeter.

This solder offers the advantages of use at low temperature on components which are sensitive to heat. Since no flux is required, there is no contamination or residue. Typical applications include connections made to heat sensitive diodes and transistors, grounding aluminum capacitors to steel chassis, electrical shielding, bonding the tantalum slug to a can of a tantalum capacitor and bonding electronic tube caps to the glass tube.

Available in paste form with a liquid hardener, Shurbond 102 offers a bonding technique with dissimilar metals where no type of soldering or brazing would be possible. For further technical data, write to the firm.

Analog Comparator

Navigation Computer Corp., Valley Forge Industrial Park, Norristown, Pa. announces the Model 522 Analog Comparator. This module compares the output of a digital-to-analog converter with analog input in the range of ±9.99 volts. The accuracy of the entire conversion, including errors in both the analog comparator and the digital-to-analog converter, is ±0.05% of ±9.99 volts.



Other 500 series modules are available for building complete binary or binary-coded-decimal converters. These converters are compatible with NAVCOR 300 Series equipment, and can be designed to meet your specific requirements.

The price of the Model 522 is $149.00, and delivery is two weeks after receipt of order. Write to the firm for information on the other 500 Series modules for A-to-D Conversion.

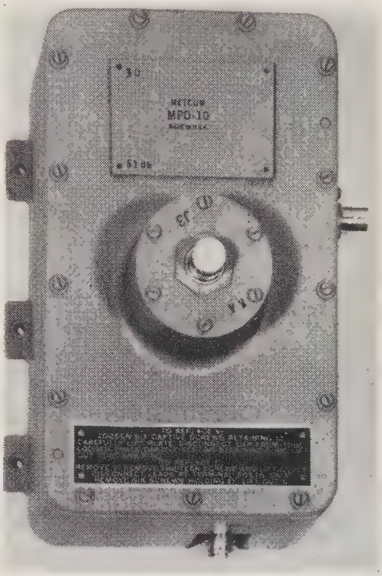
Precision Adjustable Capacitors

A new line of high stability, high precision, polystyrene adjustable capacitors is available from **Electronic Associates, Inc., Long Branch, N J.**

Called the type PSH 521 adjustable capacitor, the unit has a diameter of $\frac{5}{8}$ inch and is only $2\frac{5}{8}$ inches long. It is available in ranges of from 0.001 to 0.1 microfarad. The voltage range is 600 volts dc maximum and the temperature coefficient is 100 parts per million/°C.

High stability is a feature of this capacitor; it is rated at 0.01% per year maximum regardless of capacitance adjustment. Price is approximately $35.00.

Strip Line Duplexer

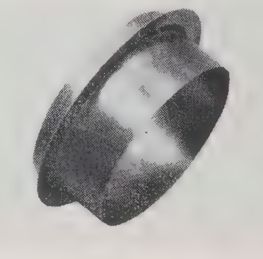


Metcom, Inc., 76 Lafayette St., Salem, Mass., offers for the first time complete strip line duplexing using gaseous-solid state techniques in the same package.

The MPD-10 covers the frequency range of 200 to 230 mcs handling 10 kw peak 200 watts average protect crystal.

Custom Designed Klystron Shields

A 600% cost reduction was achieved on the OFHC copper klystron shield shown. This shield, which was previously formed by spinning, is now drawn from flat stock by the **Electronics-Industrial Div., C. Ray Randall Mfg. Co., Inc.,** North Attleboro, Mass.

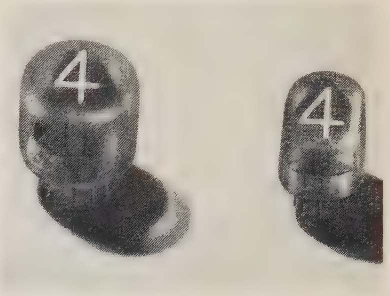


C. Ray Randall engineers design and build tools from customer part prints or help redesign parts for low cost production in the company's integrated deep drawing, stamping and machine shop facilities.

For further information on klystron shields and other electronic components and assemblies, write Mr. W. W. Wexler, sales manager at the firm.

Rectangular Nixie®

Burroughs Corp., Electronic Components Div., Plainfield, N. J., has announced the addition of a rectangular type to its Nixie Indicator Tube line. The new tube type permits the miniaturization of digital equipment utilizing in-line readout.

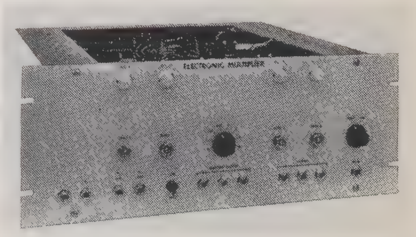


Because of the rectangular shape, individual tubes can be stacked side by side to utilize minimum panel space with no sacrifice of readability. The rectangular Nixie tube's width is over 20% less than that of the cylindrical type. The character sizes remain exactly the same. In addition, internal structural changes have reduced the tube's depth almost 25%. This provides the equipment designer greater use of behind-panel space.

For details write to the firm.

Wide Bandwidth Multiplier-Divider

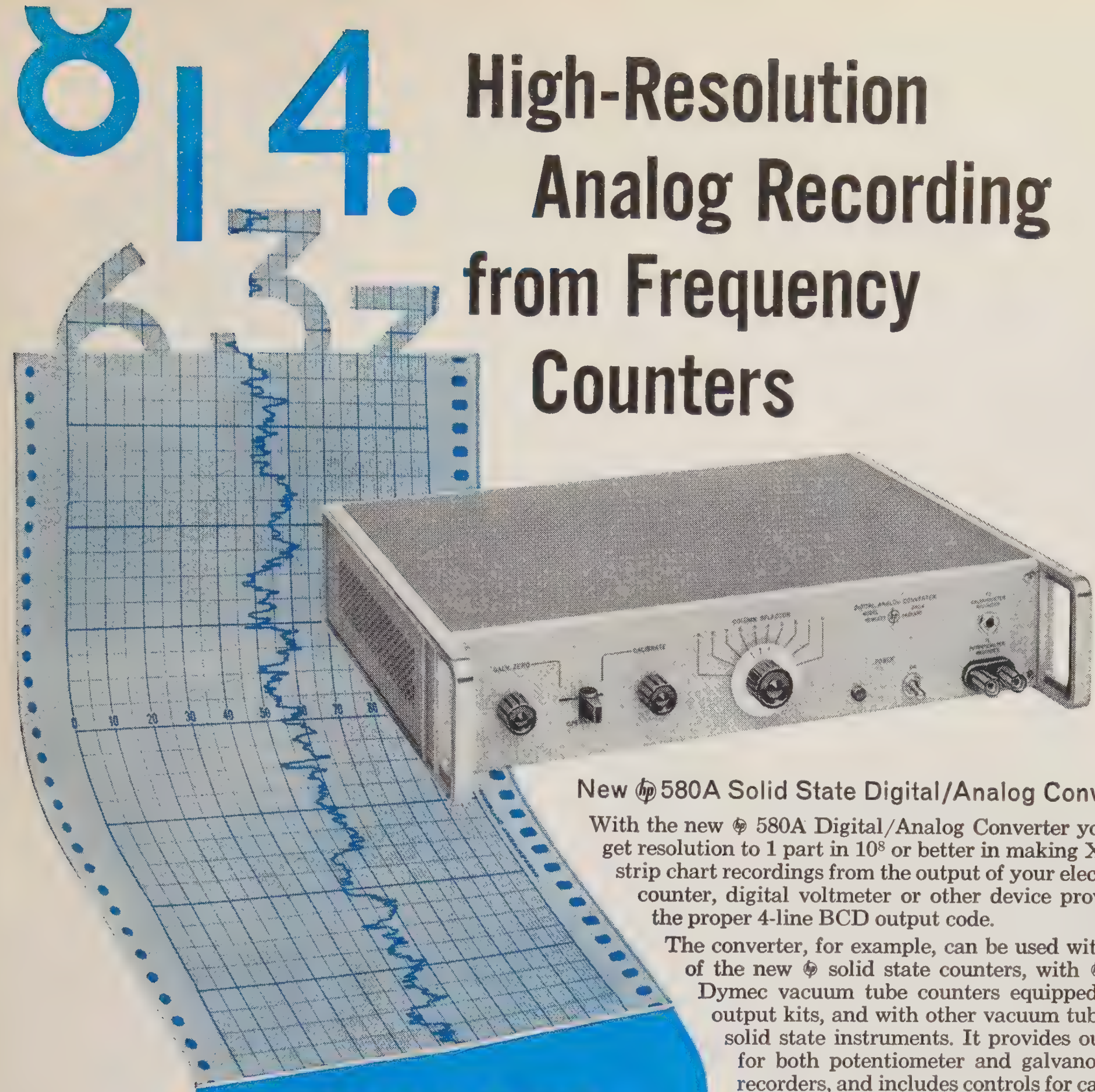
New Model MU 500F all-electronic multiplier-divider developed by **GPS Instrument Co., Inc.,** 180 Needham St., Newton 64, Mass., features wide bandwidth operation. Half power (−3db) amplitude attenuation occurs at 400,000 cps, with only 90° of phase shift at frequencies exceeding 500,000 cps. The transient response time of multiplication with a step function is less than two microseconds. For high precision analog service, the phase shift in the region 0 to 12,000 cps is less than 1°.



Fully self contained, it operates on the "quarter square" principle. Accuracy is 0.25 per cent of full scale which is ±50 volts. The high scale factor of $2xy$ permits many applications without additional external amplification. Its four-quadrant

(Continued on page 138A)

High-Resolution Analog Recording from Frequency Counters



New ⓗⓟ 580A Solid State Digital/Analog Converter

With the new ⓗⓟ 580A Digital/Analog Converter you can get resolution to 1 part in 10^8 or better in making X-Y or strip chart recordings from the output of your electronic counter, digital voltmeter or other device providing the proper 4-line BCD output code.

The converter, for example, can be used with any of the new ⓗⓟ solid state counters, with ⓗⓟ and Dymec vacuum tube counters equipped with output kits, and with other vacuum tube and solid state instruments. It provides outputs for both potentiometer and galvanometer recorders, and includes controls for calibration of the recorders.

Any three successive digits (or the righthand two) may be chosen for analog output, and selection of the least significant digits produces analog records of extreme resolution and accuracy. For example, recording three righthand digits of nine-column data results in resolution of 1 part in 10^8. Automatic zero-shift keeps the record "on-scale" at all times.

The solid state ⓗⓟ 580A accepts 4-line data, which is transferred to storage binary units within the converter on command from the counting source. The stored data is then translated and weighted to provide the proper analog output voltage or current.

SPECIFICATIONS

Accuracy:	0.5% of full scale
Potentiometer Output:	100 mv full scale
Galvanometer Output:	0 to 1 ma into 5,000 ohms or less
Driving Source:	Parallel entry 4-line BCD, 1-2-2-4 (9 digits max.) having a swing of 4 to 75 v about a source reference
Command Pulse:	Positive or negative pulse, 20 μsec or greater in width, 6-40 v amplitude
Transfer Time:	2 msec
Size:	16¾" wide, 3½" high, 11½" deep; 15 lbs.
Price:	$525.00

Data subject to change without notice
Price f.o.b. factory.

HEWLETT-PACKARD COMPANY

1501 Page Mill Road, Palo Alto, California,
Area Code 415, DA 6-7000

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8270 Mayrand Street, Montreal

7366

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 136A)

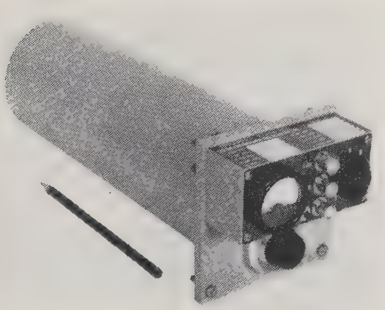
operation measures any combination of positive or negative input voltage signals, and the output voltage may be switched from minus to plus or reverse.

Overload lights indicate both overvoltage and overload. A selector switch on the front panel permits monitoring the input signals, their sum and their difference during normal operation. All amplifiers are chopper stabilized.

The Model MU 500F is recommended for application involving high speed calculations or input response, such as data correlation, data reduction, automatic control and guidance systems. Used in combination with other analog devices, it is an accurate tool for problem solutions in compressed time or in real time applications.

Miniature Frequency Standard

A compact, rugged, but highly stable quartz-crystal oscillator has been announced by **Sulzer Laboratories, Inc.,** 5526 Dorsey Lane, Washington 16, D. C. This all-silicon solid-state unit, which has been designed for use as a laboratory frequency standard, is also suitable for application in timing and synchronous communication systems. The oscillator, designated Model 5, is the commercial version of the AN/URQ-10, which was developed by this manufacturer. Its performance exceeds the specifications (MIL-F-21584A) of the military model, from which it differs only in the use of a more versatile type of mounting and the substitution of a non-ruggedized panel meter.

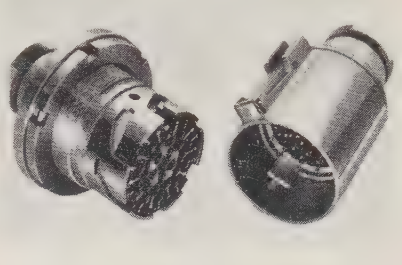


The outputs (1 volt to 50 ohms) at frequencies of 5 mc, 1 mc, and 100 kc, are guaranteed stable to 5×10^{-10} or better over 24 hours, over ambient temperatures from -10 to $+60°$ Centigrade, with power-supply variations from 22 to 32 volts (at $\frac{1}{4}$ ampere), and for any load condition. The short-term stability is better than 4×10^{-11} over 1 second, and 4×10^{-10} over 0.1 second. The output frequency is adjustable over a range of 100×10^{-9} by a front-panel control, which has a constant sensitivity of 1×10^{-10} per division.

The oscillator is $4\frac{1}{2}$ inches square by $11\frac{3}{4}$ inches deep. It can be shelf, bulkhead, or rack ($5\frac{1}{4}\times19$ panel) mounted, as desired. The cost is \$2,400.00 (1–9 units), with 10 week delivery. A companion power supply (Model 5P, same size) with over 10 hours of battery standby, is available for \$450.00. An oscillator of even higher stability (Model 2.5, same size, 1×10^{-10} per day) is priced at \$3,400.00. Complete data on these units, as well as frequency dividers, multipliers, and a new digital clock are available from the manufacturer.

Connectors

The 'Camlecon' and 'Collecon' connectors were conceived originally by **Belling & Lee, Ltd.,** Great Cambridge Rd., Enfield, Middlesex, England, and distributed in this country by **Ercona Corp.,** 16 West 46th St., New York 36, N. Y. They are based on a new principle of construction whereby each socket is individually adjusted to its mating pin by a large increment of contact pressure after engagement, permitting insertion and withdrawal forces to be restricted to better than normal proportions.

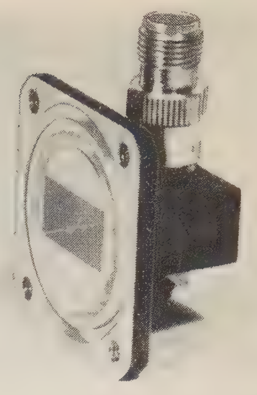


Contact is made initially by conventional plug-and-socket action, using solid round pins in divided tubular sockets, but with exceptionally low insertion and withdrawal forces. However, each pin has a gradual taper near its root, producing a slight waist, and after full engagement, a compressive force is applied to the mouth of its socket causing closure and an enormous increase in pressure on the pin. This is proportional to the amount of closure, and provided that it exceeds the minimum necessary to take care of normal tolerances, the mouth of the socket does not have to be closed completely to achieve the desired effect. In fact, this is a limiting condition, which is to be avoided since it would obviate the self-regulating feature of the design.

'Camlecon' connectors are so named because of the cam action by which the compressive force is applied to the mouth of the socket. A sliding plate, with a key-hole shaped slot in it, surrounds the socket mouth which is compressed as it enters the narrower section. In the 'Collecon' type, however, the outside wall of each socket bells outward towards the mouth, and an external collet applies the closing force by axial displacement.

The adjustment of all sockets is achieved simultaneously by external means. In the simplest pattern, a screw driver is used to actuate the mechanism, but in the more sophisticated types a combined mating and locking lever, or ring, is employed. Sealing is incorporated when it is desired to exclude the effects of variations in climatic conditions.

Waveguide Adapter



Electronic Specialty Co., Technicraft Div., 116 Waterbury Rd., Thomaston, Conn., has developed a new TNC to WR-90 transition. This adapter, available from the Technicraft Division, consists of a section of *X*-band waveguide, less than one inch long, designed with an optimum launching section from waveguide to a TNC coaxial connector. The component claims superior operating characteristics with a VSWR of less than 1.15 from 8 to 11 Cg.

The type TR-641016 is supplied with a standard choke flange and the type TR-641018 is supplied with a cover flange.

For further information contact the firm.

Toggle Switches Bulletin

The new series of panel sealed toggle switches and a unique hermetically sealed unit, which meet applicable requirements of MIL-S-3950, are fully described and illustrated in a bulletin just issued by **Electrospace Corp.,** 12 Morris Ave., Glen Cove, L. I., N. Y. Two panel sealed types provide screw terminals while the third has solder terminals. They have electrical ratings of 10 amps at 125V AC, or 30V DC, and maintain high contact pressure with fine silver contacts directly connected to leads. The hermetically sealed toggle switch with similar electrical rating is enclosed in a steel case, with glass-to-metal seals, and back-filled with dry nitrogen. It is specially designed for explosion proof and other environmental hazard applications. Bulletin No. 5400 will be sent on request.

Microwave Square Law Detector

The Bolomistor is a semiconductor bolometer-like detector developed by **MSI Electronics, Inc.,** 116-06 Myrtle Ave., Richmond Hill 18, N. Y., that derives a voltage output directly proportional to the power input. Packaged in the 1N21-1N23 type of cartridge, the B-100 series is available in 40 db and 50 db types covering the power range from -60 up to $+40$ dbm. The Bolomistor requires no bias, has an extremely short time constant and is usable in all standard crystal holders and mounts with the output voltage fed into VSWR amplifiers and/or millivoltmeters.

(Continued on page 140A)

varactors for LOW NOISE parametric amplifier designers

Microwave Associates is now producing a new series of varactors especially designed and characterized for parametric amplifier use. These new diodes have resulted from close cooperation with many of our customers as well as our own experimentation.

A new figure-of-merit called f_c' has proven to be of significant value. There is a direct correlation between this parameter and noise figure in the majority of practical amplifier designs. This figure of merit is defined as:

$$f_c' = f_c\,(-3\text{V}) - f_c\,(+1\,\mu\text{A})$$

The choice of bias levels is more useful than zero and breakdown voltages since most paramps are operated between −3 volts and +1 microampere.

Another useful parameter is the junction capacitance ratio for the above range.

$$\beta = \frac{C\,(+1\,\mu\text{A})}{C\,(-3\text{V})}$$

This parameter is related to amplifier bandwidth.

The table below illustrates suggested diode choice in the various frequency bands.

Freq. Band	Type	f_c' (kMc)	β
UHF	MA-4534	50	5.0
L	MA-4534	50	5.0
S	MA-4535	60	5.0
C	MA-4535	70	5.0

This is another example of Microwave Associates' continued effort to characterize varactor diodes for specific application and to advance the state-of-the-art. Look for improved characteristics in the future.

MICROWAVE ASSOCIATES, INC.

United Kingdom Sales: [illegible]

Other Export Sales: [illegible]

BURLINGTON, MASSACHUSETTS • WESTERN UNION FAX [illegible]

TWX: BURLINGTON, MASS. [illegible] • [illegible]

NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 138A)

It is designed for the frequency range from L through X-band.

The extended square law response makes the Bolomistor ideal for VSWR and attenuation measurements. The fast transient response permits its use for the detection and measurement of pulse as well as CW power.

Continental Expands Plant Facilities

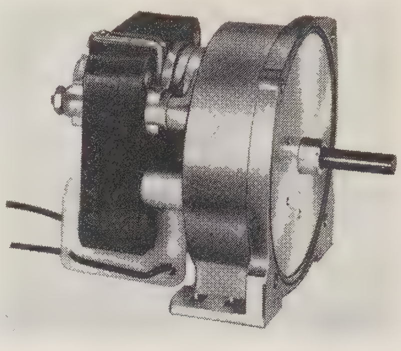
Leon Gilbert, executive vice-president of **Continental Connector Corp.,** Woodside 77, N.Y., manufacturers of precision electronic connectors for commercial and military applications, announced the termination of its exclusive sales agreement with DeJur-Amsco Corp. for the sale of Continental Connectors.

For the past few months, all sales activities have been handled directly by Continental through its own direct sales force and manufacturers' sales representatives throughout the United States. Nat Geldman will continue as national sales manager for Continental.

This move is in line with the firm's expansion program and includes the purchase of a 23,000-square-foot building adjoining its main plant in Woodside, Queens. The new sales department occupies a portion of this building.

Gear Motors

R.M.S. Motor Corp., 24 Charlotte St., Binghamton, N. Y., a division of Endicott Coil Co., Inc., announces the development of a line of milli-horsepower gear motors with speeds down to $\frac{1}{5}$ rpm and torque up to 800 inch/pounds.

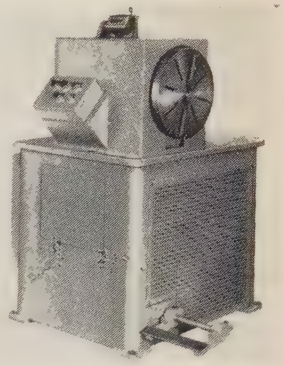


The motors are of the shaded-pole type and are said to provide more torque and less temperature rise, size for size, than similar units.

The motors have precision gears, zinc alloy gear housing and self-aligning bearings. They can be face or foot-mounted in any position without modification.

They are available for 6 to 440 volt-ac operation, 50 and 60 cps. Output shafts are 1″ long by $\frac{1}{4}$″ or $\frac{5}{16}$″ or $\frac{3}{8}$″ diameter, with other sizes available on request.

Heavy Duty Winder



A new heavy duty winder with 2-speed torque ranges for hand wound distribution transformers using wire sizes as heavy as No. 2 AWG is offered by **Geo. Stevens Mfg. Co., Inc.,** Pulaski Road at Peterson, Chicago 46, Ill. Ample torque permits more than 1 conductor to be wound simultaneously. A 2-speed transmission permits adjustable speed ranges of 20 and 40 RPM at full HP rating of motor. Maximum coil OD is 24″ and main spindle diameter $2\frac{7}{16}$″.

Control panel is conveniently positioned. A 14″ diameter face plate is furnished for acceptance of mandrels and adaptors. Model 1010-A has vista green industrial finish, non-electric 6-digit direct readout additive counter, magnetic brake safety feature and motor. Dimensions are 33″ L×36″ W×48″ H. Net weight is 1,500 lbs. Delivery 3–4 weeks. Price approximately $3,500.00.

Solid State DC Power Modules

Technipower, Inc., 18 Marshall St., South Norwalk, Conn., now has available its new catalog No. 362, which reflects Technipower's expanded line of miniature solid state dc power supplies.

Three general categories are listed. The Standard Line covers a range of from 3 to 240 vdc, capacities up to 300 watts, regulation accuracy 0.05 or 0.5%, and ripple 1 or 5 mv RMS.

The High Temperature Line covers a similar range at similar regulation accuracies, but utilizes silicon transistors and tantalum capacitors to permit operation at temperatures to 100°C and to give outstanding performance at all temperature levels. The Unregulated Line offers a similarly wide range of supplies to meet applications where regulation is not an important factor.

The catalog also provides complete specifications, dimensions, prices, heat sink requirements and other application data.

For a free copy, direct request for Catalog 362 to the firm.

ANTENNA PEDESTAL
SCR 584 - MP 61B

Full azimuth and elevation sweeps 360 degrees in azimuth. 210 degrees in elevation. Accurate to 1 mil. or better over system. Complete for full tracking response. Angle acceleration rate: AZ, 9 degrees per second squared EL, 4 degrees per second squared. Angle slewing rate: AZ 20 degrees per sec. EL. 10 degrees per sec. Can mount up to a 20 ft. dish. Angle tracking rate: 10 degrees per sec. Includes pedestal drives, selsyns, potentiometers, drive motors, control ampildynes. Excellent condition. Quantity in stock for immediate shipment. Ideal for missile & satellite tracking, antenna pattern ranges, radar system, radio astronomy, any project requiring accurate response in elevation and azimuth.
Complete description in McGraw-Hill Radiation Laboratory Series, Volume 1, page 284 and page 209, and Volume 26, page 233.

SCR 584 RADAR AUTO-TRACK
3 CM & 10 CM. Our 584s in like new condition, ready to go, and in stock for immediate delivery. Used on Atlantic Missile Range, Pacific Missile Range, NASA Wallaps Island, A.B.M.A. Write us. Fully Desc. MIT Rad. Lab. Series, Vol. 1, pps. 207-210, 228, 284-286.

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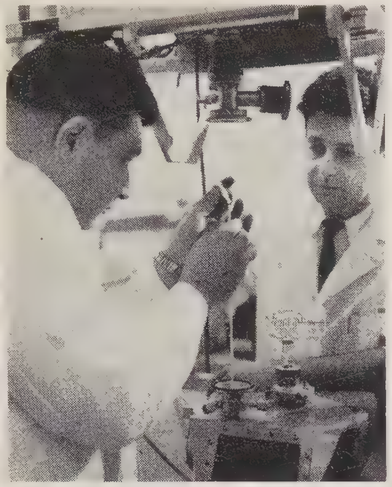
Magnetic Shield Data Sheet

Data Sheet 157, illustrating and describing a 4-layer non-retentive non-shock sensitive Netic Co-Netic magnetic shield design for effectively shielding low level fields, is available from **Magnetic Shield Div., Perfection Mica Co.,** 1322 N. Elston Ave., Chicago 22, Ill.

Cadmium Selenide

A convenient new laboratory method for preparing ultra-pure cadmium selenide and related compounds has been developed by scientists of **International Business Machine Corporation's Thomas J. Watson Research Center,** Yorktown, N. Y. Cadmium selenide is of considerable current interest because of its excellent properties as a photoconductor.



The new process permits a low temperature synthesis of CdSe directly from the elements for the first time. Earlier attempts at direct synthesis required high temperatures and frequently produced explosive reactions. In the new method, very fine powders of Cd and Se are heated slowly to a temperature of 450°C in a high vacuum. The successful method is a result of the discovery that the powders must be composed of particles smaller than a certain critical size, and that the heating rate must be not greater than 0.5°C per minute. Under these conditions, the elements react completely to form CdSe. A similar process has been found to be applicable to a number of other compounds, including CdS, CdTe, ZnS, ZnSe and ZnTe.

The new preparation technique, along with results of a variety of other chemical studies of CdSe, were reported by IBM scientists Arnold Reisman and Melvin Berkenblit at an American Chemical Society symposium in Washington.

In their initial attempts to find a better method of preparing CdSe, Dr. Reisman and Mr. Berkenblit found that no reaction occurred between Cd and Se until they were heated to temperatures 600 to 700°C above their melting points. Further work showed that a tenacious, non-volatile skin of CdSe formed on the surface of a Cd pellet as soon as it melted at about 320°. The two chemists then worked out the phase diagram for the CdSe system, which showed that CdSe was practially insoluble in both Cd and Se up to temperatures of 900 to 1000°C. Thus the CdSe skin could not dissolve in the Cd and, with its much higher melting point, remained intact up to the 900 to 1000° temperature range, preventing any further reaction.

This finding suggested that a way to make CdSe at lower temperatures would be simply to react the two elements in the form of powders of small enough particle size so that each particle would be entirely used up in forming the reaction-inhibiting skin of CdSe. Using 325 mesh powder, the IBM chemists found that a complete reaction was produced at 450°C. The process is extremely reliable, and hundreds of batches of high-purity, fully-reacted CdSe have been made.

An additional discovery made by Dr. Reisman and Mr. Berkenblit is also of practical interest. Early in the course of their experiments they noticed that silica containers in which reactions of CdSe were studied became severely corroded unless the pressure in the container was less than about 10^{-4} mm Hg. Further work showed that the corrosion was due to the presence of CdO. This result suggested a good method for obtaining adhesion between a sintered layer of CdSe and a silica or silica-based substrate in photoconductive devices. A few tests showed that a small amount of oxygen introduced into the atmosphere during sintering of CdSe layers on glass substrates produced good bonding by means of CdO corrosion of the glass.

(Continued on page 142A)

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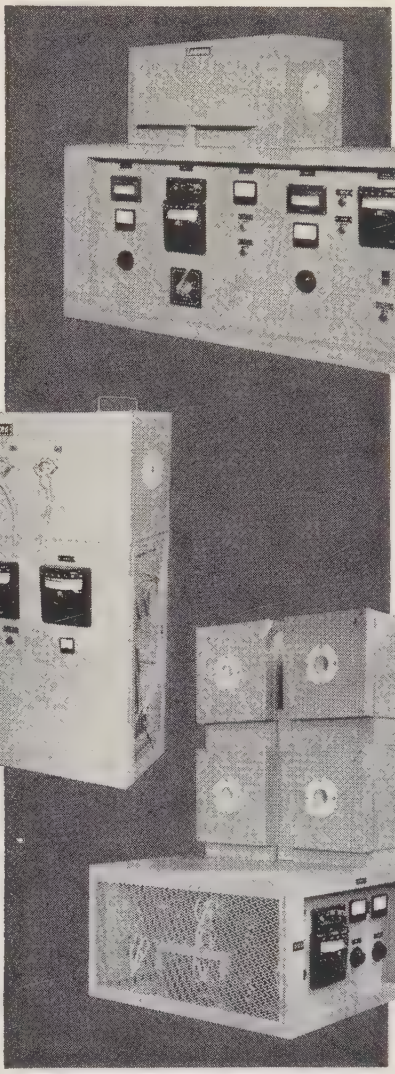

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NEWS New Products

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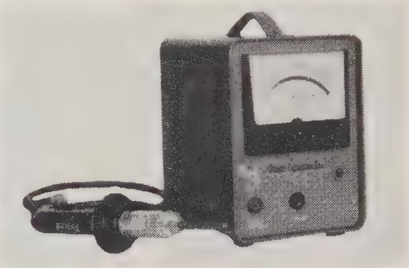
(Continued from page 141A)

Kilovoltmeter

Plastic Capacitors, Inc., 2620 N. Clybourn Ave., Chicago, Ill., is now marketing Model VM105 kilovoltmeter. A 50 microampere meter movement with a knife edge pointer and mirrored scale provides voltage ranges of 0 to 1, 0 to 5, 0 to 10 and 0 to 20 kv. Full scale accuracy is 2%. Meter protection and the high voltage cable and probe are provided.



Cabinet size is 6 by 8 inches base and 8 inches high. Finish is a medium gray hammertone. Weight is seven pounds—shipping weight is eleven pounds.

For descriptive literature write to the firm.

Semiconductor Activation Analysis

Activation Analysis, a bulletin for the semiconductor industry, explains the activation analysis technique, and lists applications in the industry including research and quality control. This ultra-sensitive analytical technique can be used to determine the amounts of phosphorus, antimony, arsenic, indium, gold and gallium in these electronic components. Bulletin also describes General Atomic's exploratory study offer. A list of elements that can be determined, and their estimated instrumental detection sensitivities and cost per analysis is also included. Activation Analysis Service, General Atomic Div., **General Dynamics Corp.,** P.O. Box 608, San Diego 12, Calif.

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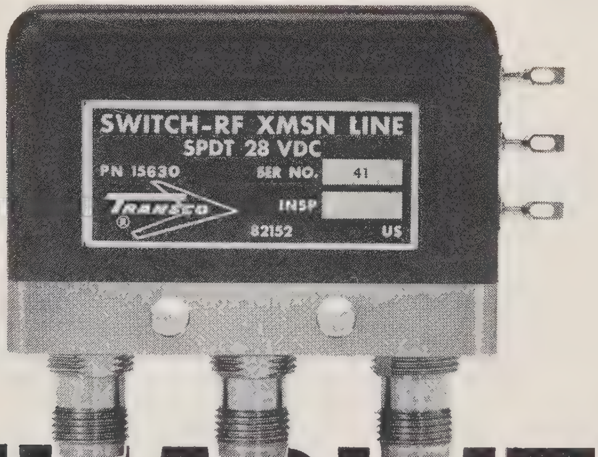

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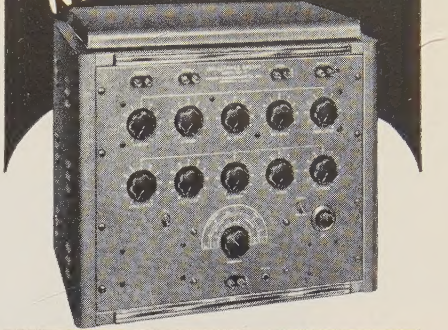

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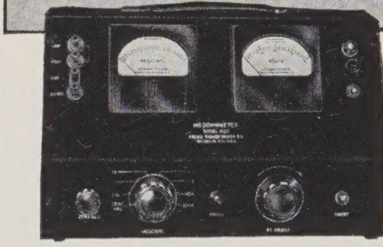

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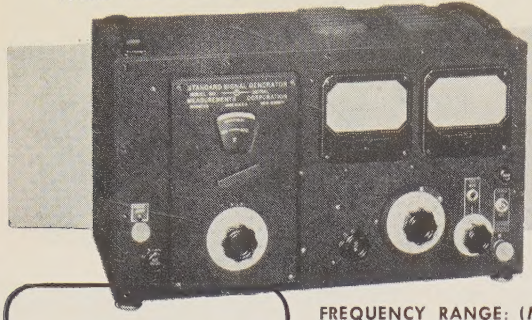

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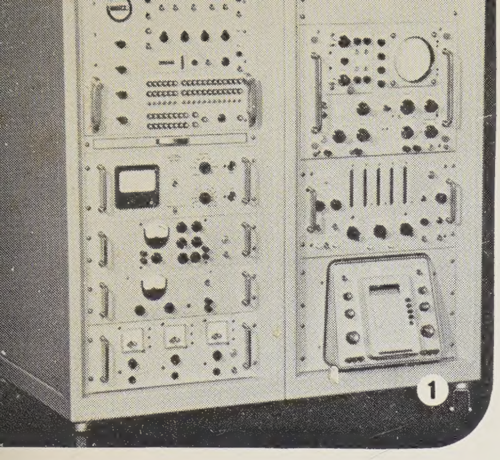
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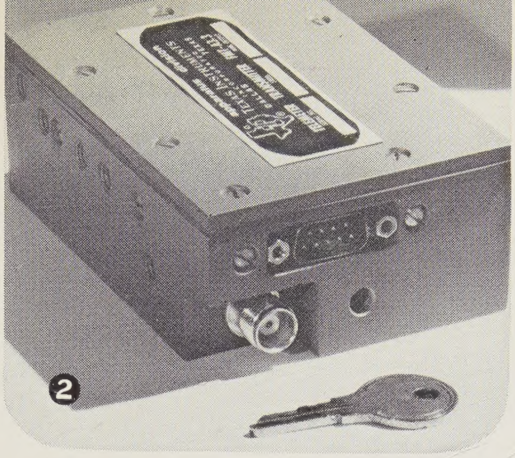
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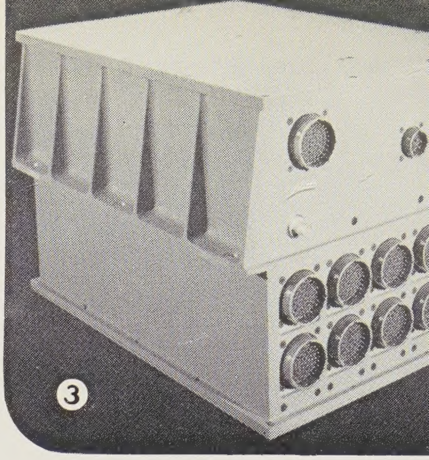
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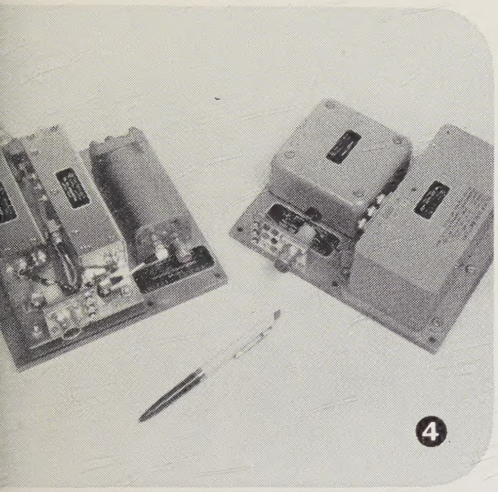
HERE'S HOW TI SOLVES SPACE COMMAND/GUIDANCE PROBLEMS

With **experienced** systems engineering staff–**complete** manufacturing capability–**product-proved** research and development laboratories–plus **time-tested** equipments now operational, some of which are:

1. Command System Ground Checkout Equipment for Jet Propulsion Laboratory, California Institute of Technology, to test Ranger 3-5, NASA lunar probe.
2. Solid-State FM/FM Telemetry Transmitters operated in Mercury spacecraft flights.
3. Flight Data Encoder uses high/low-level PCM telemetry system . . . with ±0.5% accuracy, nulled-out drift. A similar 70-channel system has been supplied to Jet Propulsion Laboratory for Mariner A.
4. Solid-State UHF Beacon Transponder made possible missile tracking by MIT Lincoln Laboratories Millstone radar.
5. Digital flight controller/programmer in Douglas Aircraft's Delta Launch vehicle helped orbit NASA weather satellites Tiros II and III, communication satellite Echo I, space probes Explorer X and XII.
6. 3-Channel Parametric Amplifier—Low-noise operation for C-Band monopulse satellite tracker for Bell Telephone Laboratories.
7. Digital Command Decoder for Ranger 3-5 lunar probes.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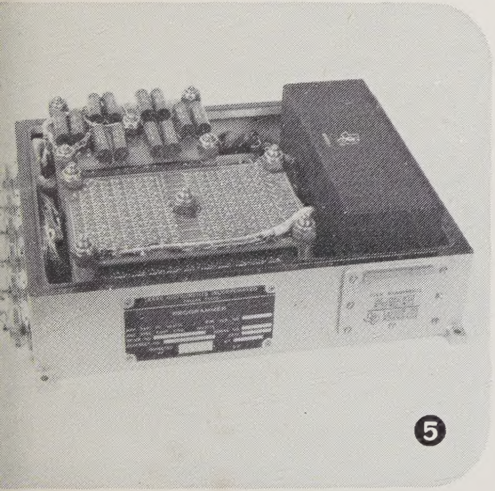
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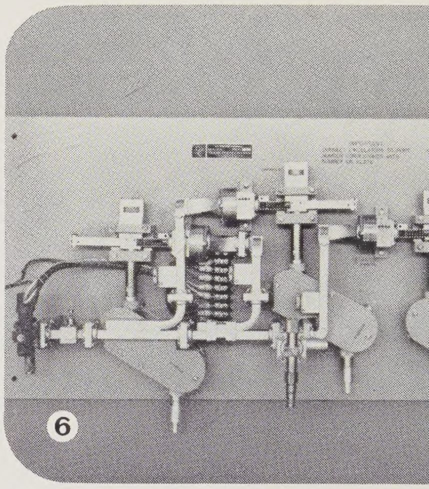
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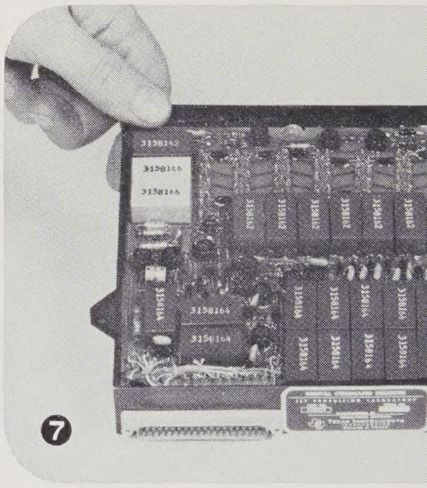
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For information on your specific command/guidance requirements, contact **MARKETING DEPARTMENT.**

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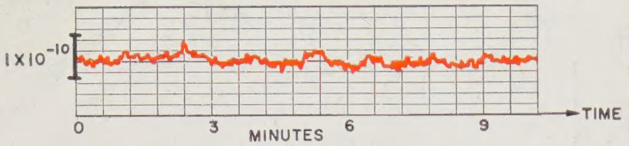
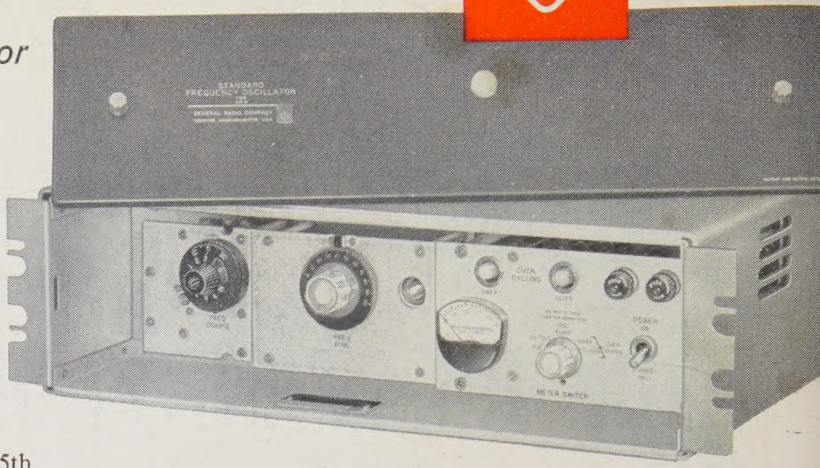
One Part in 10^{10} Stability

from this Standard Frequency Oscillator priced at only $1550



Intercomparison of two 1113-A Standard-Frequency Oscillators measured with 1-second samples. The short-term instability of one oscillator is less than this combined instability by $1:\sqrt{2}$.



The 1113-A Standard-Frequency Oscillator uses a 5-Mc, 5th overtone, AT-cut crystal in a modified Gouriet-Clapp circuit. This crystal has a Q in the range of 2 to 3 million, permitting a high degree of decoupling between itself and its maintaining circuit. Thus, short-term frequency variations are minimized. High Q, along with extreme care to avoid drift-provoking contamination during processing results in a crystal with excellent over-all stability. Crystal drive power is carefully maintained at a low value to minimize aging and drift caused by high drive levels. AGC feedback maintains crystal drive level within 10% for changes up to 2:1 in tube transconductance. A two-stage oven maintains temperature changes to 0.001°C and frequency cycling to less than 1 part in 10^{10}. For operational checks, a built-in meter measures oscillator bias, rf output, plate current, inner-oven temperature and outer-oven temperature. The oscillator tube is operated at a low transconductance and low heater temperature to retard cathode-interface effects. D-C heater voltages are filtered to minimize 60-cycle fm; finally, both heater and plate supplies are regulated to the point that the instrument is practically independent of line-voltage variations.

Type 1113-A STANDARD-FREQUENCY OSCILLATOR

OUTPUT: 1v rms into 50 ohms at 5 Mc

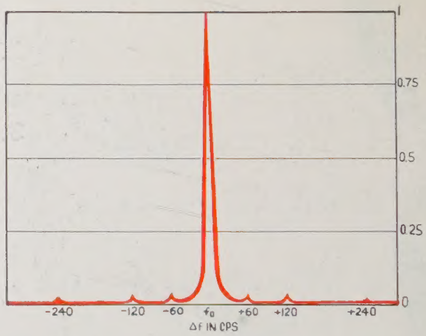
STABILITY: Aging — Better than $\pm 5 \times 10^{-10}$ per day, averaged over 10 days, after 60 days of operation. After 1 year, average drift is less than 2×10^{-10} per day.

Short-term — Better than 1×10^{-10} per minute, measured with 1-second samples

Ambient — Less than 1×10^{-10}/°C (5×10^{-8} for 0-50°C)

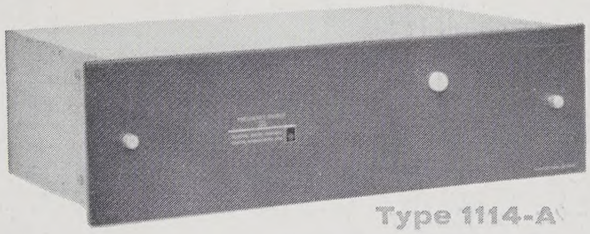
Line — Less than 1×10^{-10} for 105-130 volts

PRICE: $1550



Power spectrum of 1113-A signal multiplied to 23,900 Mc as measured at NBS Boulder Laboratories

Companion Frequency Divider



Type 1114-A Frequency Divider

The 1114-A Frequency Divider accepts a 5-Mc input signal to produce output frequencies at 1 Mc, 100 kc, 10 kc, 1 kc, and 100 cps. Additional plug-in units are available with outputs at 400 and 60 cps. All circuits are "fail-safe". Outputs are sine waves, with square waves also available at 10 and 100 kc.

INPUT: Either 5 Mc, 1 Mc, or 100 kc at 50Ω, 1v ± 50%

OUTPUT: 1 volt at 5 Mc (with 5 Mc input), 1 Mc, 100 kc, 10 kc, 1 kc, 100 cps. 400 cps and 60 cps with optional plug-in units. Square waves at 100 kc, 10 kc (7v p-p)

SPURIOUS SIGNALS: Better than 34db down

PRICE: $950; 400-cycle Plug-in Unit, $85; 60-cycle Plug-In Unit, $115.

These instruments plus the G-R Syncronometer, interconnected in a relay rack, comprise the Type 1120-A Frequency Standard, $3715.

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